Bulletin
of
The Geological Society of America

VOLUME 57 September 1946 NUMBER 9

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Subscription, $10 per year.

Publication Office: Mt. Royal and Guilford Aves., Baltimore 2, Md.

Communications for publication should be addressed to The Geological Society of America, Dr. H. R. Aldrich, Secretary, 419 West 117th Street, New York 27, N. Y.

NOTICE.—Four weeks notice of change of address is necessary. In accordance with the rules established by the Council, claims for non-receipt of the preceding number of the Bulletin must be sent to the Secretary of the Society within three months of the date of the receipt of this number in order to be filled gratis.

Entered as second-class matter in the Post-Office at Baltimore, Md., under the Act of Congress of July 16, 1894.

Accepted for mailing at special rate of postage provided for in Section 1103 Act of October 3, 1917, authorized on July 8, 1918.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 57, PP. 781-796, 2 PLS., 2 FIGS. SEPTEMBER 1946

CONTINENTAL-MARINE MISSISSIPPIAN RELATIONS IN NORTHERN PENNSYLVANIA

BY BRADFORD WILLARD

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ABSTRACT

The marine Mississippian of northwestern Pennsylvania meets and merges in north-central Pennsylvania with the continental Mississippian spread from the northeast. At their junction, the two facies are confined between the overlying Olean or Pottsville spheroidal-pebble conglomerates of the basal Pennsylvanian and the underlying Devonian. The latter is represented by the Mount Pleasant red shale of the continental Catskill facies to the east and the youngest marine Devonian, the Oswayo formation, to the west. The marine Mississippian consists of the Knapp formation including the Kushequa shale and Marvin Creek "limestone". The Knapp is largely composed of sandstones and conglomerates, the latter distinguished by their discoidal, milky quartz pebbles and occasionally a jasper phenoclast. The marine Mississippian yields Kinderhook fossils. The continental Mississippian, carrying the *Triphyllopteris* flora, consists of the gray Pocono sandstones and pebble beds which to the east are overlain by the Mauch Chunk red shale, not recognized in north-central Pennsylvania. In the region of marine-continental transition, the Mississippian system is represented by approximately 150 feet of beds. The marine fossils gradually disappear eastward as the discoidal-pebble conglomerates and sandstones of the Knapp merge with the Pocono sandstone and conglomerate.

INTRODUCTION

GENERAL STATEMENT

The Mississippian system occurs throughout most of the northern counties of Pennsylvania. Before field work was interrupted by the war, the author had made some studies of this system incidental to his work on the Devonian. During the field season of 1945, he resumed work with the Pennsylvania Topographic and Geologic Survey and devoted his studies solely to the Mississippian. The results interpret the marine-continental relations within the system. Prior to the present work, the marine Mississippian of northwestern Pennsylvania and the continental in the northeast were well known, but correlation between them was unsatisfactory.

PREVIOUS WORK

The generalized late Paleozoic sequence in north-central Pennsylvania is:

Pennsylvanian	Olean conglomerate
Mississippian	Knapp formation
Devonian	Catskill red beds
	Oswayo marine sandstone

Previous workers in the Mississippian in northern Pennsylvania contributed some accurate knowledge, and made some errors. One can commend Rogers (1858), who published an approximation of the truth. The county reports of the Second Pennsylvania Survey are more comprehensive. Those by I. C. White (1881a; 1881b; 1883) and Carll (1880; 1883) are particularly good. White's Mississippian sequence is still useful. To Carll goes credit for distinguishing "flat" from "round" pebble conglomerates. Those Second Survey geologists who mapped Mauch Chunk red beds across northern Pennsylvania (Sherwood, 1878; 1880 *et al.*) published an error that can only now be erased, although partly righted by Fuller (1903), Fuller and Alden (1903), Butts (1910), and others. Early workers tried to make all late Paleozoic sequences conform with that in the Anthracite Fields: Pottsville conglomerate, Mauch Chunk red shale, Pocono sandstone. Some correlated the Pottsville with the Olean ("Garland" or "Sharon") and assigned the highest underlying red beds to the Mauch Chunk. Others failed to distinguish between Olean and Knapp conglomerates, either through error or nonacceptance of Carll's findings. Some Second-Survey maps indicate Pennsylvanian where they should show Mississippian, Mississippian in places occupied by the Devonian, as the following interpretations illustrate

	Present Survey	Second Survey, incorrect (No Pennsylvanian present, or conglomerates not separated):	Second Survey, correct (Pennsylvanian present and conglomerates separated):
P	Olean		Garland
M	Knapp	Pottsville	Sub-Garland
D	Catskill	Mauch Chunk	Catskill
	Marine beds	Pocono	Chemung

The author's (1939) studies of Devonian marine-continental relations in Pennsylvania have been published. The Mississippian system in our northern counties is

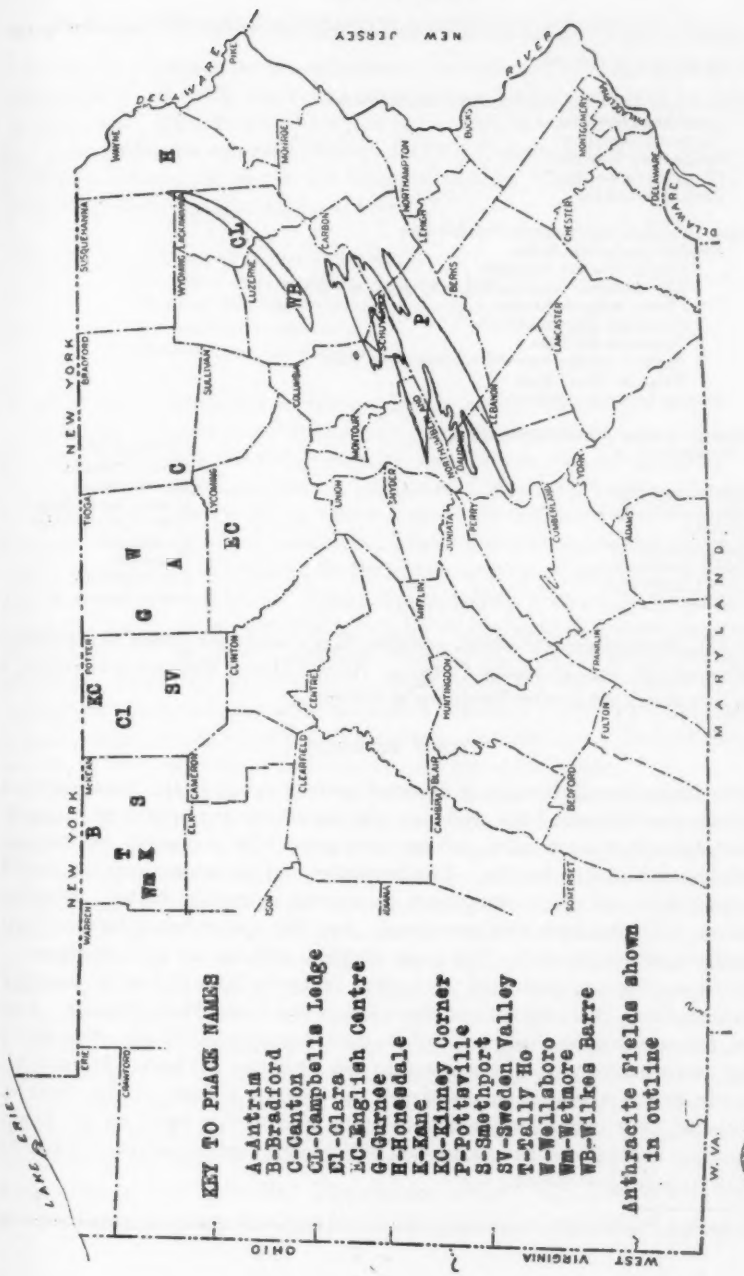

FIGURE 1.—*Outline map of Pennsylvania*

so analogous to the Devonian and so intimately related thereto that the latter system should be briefly reviewed:

Marine Upper Devonian, northwestern Pennsylvania
- Conewango formation
- Conneaut formation
- Canadaway formation
- Chemung formation
- Portage formation[1]

Upper Devonian, northeastern Pennsylvania
- Catskill continental facies
  - Mount Pleasant red shale
  - Elk Mountain cross-bedded, gray-green sandstone
  - Cherry Ridge red beds
  - Honesdale gray sandstone
  - Damascus red beds
  - Shohola red and non-red sandstone and shale
  - Delaware River flags
- Portage (marine) sandstone

Devonian marine-continental relations

Marine (west)	Continental (east)
	Mount Pleasant
Upper Conewango	Elk Mountain
Lower Conewango	Upper Cherry Ridge
Conneaut	Lower Cherry Ridge
Upper Canadaway	Honesdale
Middle Canadaway	Damascus
Lower Canadaway	Upper Shohola
Chemung	Lower Shohola

The Elk Mountain cross-bedded, greenish, flaggy sandstone passes westward into the lithologically similar marine Oswayo. As the Mount Pleasant pinches out, a hiatus terminates the marine Devonian to the west.

FIELD METHODS

North-central Pennsylvanian is dissected plateau country; the Mississippian is found near the hilltops. Dips are so low that we assume the beds to be horizontal. Field studies called for detailed sections on as many hills as possible, but measurements were not always feasible. Conglomerates and sandstones capping the hills make poor farmland which, abandoned, grows over in scrubby timber. Float and talus from the higher beds hide lower ones. Near hilltops, stream gullies are absent or shallow and float-choked. The most complete sections are on hills crossed by roads. Ascending one side until the highest Pottsville (Olean) float or outcrop is found establishes the approximate elevation of the basal Pennsylvanian. From ledges, gutter exposures, soil peculiarities, float, topography, or any other data, a section can often be worked downward to the Devonian red beds. Sometimes, a check can be run where the road descends the opposite hillside. If the Olean has been eroded, it is sometimes possible to build up a section based on the Knapp. This method of study was not carried east of Wyoming County because of increasing effect of Appalachian folding.

[1]The term "group" has been applied to these units, the lower two of which are not exposed in the northwestern counties.

MARINE MISSISSIPPIAN SEQUENCE, NORTHWESTERN PENNSYLVANIA

The marine Mississippian in northwestern Pennsylvania has been summarized by Caster (1934). He (1934) and Fettke (1938) have published résumés of the literature on the system. A maximum thickness of 500 to 600 feet is recorded. Present problems concern changes eastward through McKean County, where the system thins to between 100 and 200 feet of the Knapp formation. Caster (1934) in the table facing p. 63 summarizes the Knapp as follows:

Cobham conglomerate member	Knapp formational suite
East Kane shale member	
Wetmore conglomerate member	
Kushequa shale member	
(Marvin Creek limestone zone)	

Not all of these subdivisions are relevant to the present discussion.

The Knapp is characterized faunally by a marine assemblage including *Syringothyris angusta* Simpson, *S. randalli* Simpson, and *Rhynchospira scansa* (Hall). With the invertebrates are fish fragments, carbonized vegetation, fucoids. Some of the last resemble *Fucoides graphica*, others suggest the Silurian fossil, *Arthrophycus*. Lithologically, the Knapp is medium to coarse to pebbly sandstone, brown, occasionally olive brown; it weathers darker brown or gray. Deposition of secondary silica on the sand grains is rare. The sandstone is usually impure, particularly where it forms the matrix of conglomeratic layers; bedding is flaggy to massive, occasionally cross-bedded, but less pronounced than the Devonian Elk Mountain and Oswayo sandstones. Mud-chip layers abound; ripple marks are not common; micaceous sandstones are rare, shale and siltstone bands occasional. Limonite is usually present as stains, films, shells, or geodes, particularly near the base. Despite apparent porosity, water seepage is not uncommon at the top of the Knapp.

Of particular interest are conglomerates in the Knapp. They may be absent, but sections usually include at least one prominent bed. These have been called "flat-pebble conglomerates" in distinction from the "round-pebble conglomerate" of the Olean or basal Pennsylvanian. An unusually coarse example shows near Tally Ho on Wintergreen Run in southwest McKean County (Pl. 1, fig. 1). The matrix is a characteristic brown to gray Knapp sandstone without secondary silica deposition on the sand grains. Most of the pebbles are milky quartz, ellipsoidal; the greatest diameter of some measures 1½ inches. Dark-red, mottled, porous, jasper pebbles of similar size and shape here make up about 5 per cent of the total, an unusually high proportion. One sandstone pebble was found. This outcrop demonstrates the shape of the pebbles and the dominance of milky quartz, distinctive characteristics of the conglomerates of the Knapp. At Wetmore in southwestern McKean County, an exposure of the Knapp on the railroad half a mile south of the village is the type locality of Caster's (1934) Wetmore conglomerate member (Pl. 1, fig. 2). The texture is finer than that at Tally Ho. The pebbles, seldom more than half an inch in greatest diameter, tend to be ellipsoidal. The somewhat cross-bedded rock is fairly

well sorted and unusually pure for the Knapp, which may explain considerable secondary silica on the sand grains.

Near the base of the arenaceous Knapp in McKean and western Potter counties, the Kushequa shale is usually present. This shale is clayey, buff, brown, or gray and weathers yellow, streaked with gray. Ferruginous bands are common along joints. Interbedded sandstones are usually olive gray and fine-textured. Fossils include Knapp invertebrates and carbonized plants. The lower Knapp is further diversified by lenses of the Marvin Creek "limestone", a coquinite. This rock of comminuted shells firmly cemented is extremely hard, but its solubility causes it to weather readily to cavernous, brown blocks.

CONTINENTAL MISSISSIPPIAN SEQUENCE, NORTHEASTERN PENNSYLVANIA

The continental Mississippian is best developed in the Anthracite Fields in northeastern Pennsylvania (Fig. 1). The facies is divided into the Mauch Chunk formation above, the Pocono below. Both carry the *Triphyllopteris* flora in distinction from the *Archaeopteris* flora of the continental Devonian.

The distribution of the Mauch Chunk is the more restricted. From a maximum of at least 3300 feet in the hard-coal fields, it thins northwestward and disappears as it reaches Tioga County. Its geographic limits are indicated in a section in northern Lycoming County at English Centre along Highway 84:

	Thickness (Feet)
a. Pottsville conglomerate	
b. Mauch Chunk red shale	40
c. Pocono, coarse, gray sandstone and some greenish sandstone, flaggy to massive	280 min.
d. Catskill red beds	

and another in southwestern Bradford County southeast of Canton along the northwestern rim of the Barclay coal basin:

	Thickness (Feet)
a. Pottsville	
b. Mauch Chunk red shale	55
c. Pocono sandstone	150
d. Catskill red beds.	

Northwest of these sections accepted evidence of any Mauch Chunk is absent, although a doubtful trace was found in western Tioga County near Gurnee. (*Cf.* Fuller, 1903, p. 2.) The Mauch Chunk in the southeastern Anthracite Fields is a sequence of red shales and sandstones (*cf.* Barrell, 1907) and occasional gray or greenish strata. In the Northern Anthracite Field, in Susquehanna, Wayne, Lackawanna, and Luzerne counties, the formation thins markedly. The Mauch Chunk disappears beneath the basal Pennsylvanian, the Pottsville, along the southeast side of the field and reappears on the northwest side, changed in lithology and thickness. Years ago I. C. White described from Campbells Ledge, on the northwest side of the basin, what he believed to be this modified Mauch Chunk (1883, p. 157): "Mauch Chunk, No. XI, sandstone, flaggy, greenish and sandy shales, . . . 150′ ". He went on to amplify his ideas on these beds (1883, p. 160):

"I have referred these greenish-gray, sandy beds to the horizon of the *Mauch Chunk shales, No. XI*, although there is a *complete absence of red shale* at this locality. It is true that at Mauch Chunk and elsewhere there is always much gray or greenish rock in No. XI besides the characteristic *red shale*."

The exposure is covered today, but other sections along the northwest border of the basin tally with White's description. If there were no other information, this supposed Mauch Chunk might be dismissed as higher Pocono, but the beds immediately under the Pottsville along the southeast border of the basin are similar. Their assignment to the Mauch Chunk rather than to the Pocono is obvious from the following composite of sections east of Wilkes-Barre in southeastern Luzerne County:

	Thickness (Feet)
Pottsville, conglomerate, may have at its base a few inches of coal, fire clay and black shale.	
DISCONFORMITY. Erosional, surface of underlying beds wavy.	
Mauch Chunk	
a. Sandstone and shale, interbedded, brown, weathers rusty, thickness varies, average	30
b. Red and green or gray-green sandstones, interbedded	400
c. Red shale; the overlying non-red portion stops abruptly at this unit	2500±

Comparison of the foregoing Mauch Chunk with White's description indicates that member "a" and in part "b" of the nonred, upper part east of the basin may continue across to the west side. Thickening may be attributed to intercalation of red in member "b", a change conformable to the increase in red in this part of the formation to the south and east. Since this basin is the northern limit of the formation in this longitude, the thin, red Mauch Chunk already mentioned in Bradford and Lycoming counties is the northward extension of the main body of the formation in the main Anthracite Fields, not that of the Northern Field.

Unlike the abruptly thinning Mauch Chunk, the Pocono thins gradually westward and northwestward from the Anthracite Fields until in Potter County it merges with the marine Knapp formation. Among the easternmost exposures of the Mississippian bordering the Northern Anthracite Field in Wayne, Susquehanna, Luzerne, and Lackawanna counties, the Pocono is massive to platy sandstone, conglomerate, or sandstone with scattered milky quartz pebbles. Some beds are olive gray, but shades of gray are commonest. Thicknesses range from only 48 feet in the north to over 1000 in the south.

The formation was extensively studied in this area by I. C. White (1881a; 1883). Most of White's findings stand. There is disagreement over his Griswolds Gap conglomerate, described as a coarse, white, quartz pebble rock in the base of the Pocono. Six sections across Moosic Mountain west and northwest of Honesdale along the Wayne-Susquehanna county boundary and southward including the type locality failed to produce this member. The Pottsville in this region is coarse conglomerate of milky quartz pebbles up to 3 inches in diameter, well rounded and sorted. Among them are occasional dark chert pebbles. One suspects that White misidentified the Pottsville. The writer (1939) accepted the Griswolds Gap conglomerate.[2]

[2] In the writer's "Devonian of Pennsylvania".

MISSISSIPPIAN LIMITS

UPPER LIMIT

The upper limit of the Mississippian system across northern Pennsylvania is established in the east by the Pottsville conglomerate, in the west by the Olean conglomerate. Both of these early Pennsylvanian continental conglomerates underlie the coal measures; each is characterized by spheroidal, milky quartz pebbles, but no jasper. In this they are distinguished from the conglomerates of the Knapp. The Knapp and Olean conglomerates may be compared 1½ miles north of Kane in McKean County where deforestation of a hillside has exposed these rocks along Route 68. The Olean crops out as massive sandstone, angular to subangular grained, with scattered pebbles and pebble bands. The light-gray rock retains its color on weathering but becomes pitted. About 100 feet below the Olean the Knapp conglomerate is exposed. It carries both spheroidal and ellipsoidal quartz pebbles in a brownish matrix which weathers light gray. Usually, the sand grains of the Olean are faced by secondary silica, rarely are those of the Knapp. Consequently, a fresh Olean surface glistens and flashes in the sunlight; the Knapp is dull.

The disconformable nature of the Pennsylvanian-Mississippian shows in a Pottsville-Pocono contact exposed along State Highway 44, 3–3½ miles southeast of Sweden Valley in the State Forest in southern Potter County:

	Thickness (Feet)	(Inches)
Pottsville, conglomerate, spheroidal pebbles with average diameter of ¾ inch, weathers brown, many plant fragments.		
DISCONFORMITY		
Pocono		
a. Sandstone, massive, brown, brown-weathering, no pebbles	20	
b. Shale, yellow to rusty, clayey, limonitic geodes and shells, thin green sandstone bands	22	
c. Shale, reddish, may be from weathering of limonite	0	4
d. Shale similar to "b"	7	
e. Shale, red	0	5
f. Shale, again like "b" and "d"	15	
g. Sandstone, green, may be Oswayo or Elk Mountain.		

The Olean in the west and the Pottsville in the east are not sharply distinguished except geographically. They lie in disconformity upon first the Knapp and then the Pocono from west to east. In the Anthracite Fields, the Pottsville rests disconformably on the Mauch Chunk except where the Mauch Chunk reaches its maximum thickness in the Southern Anthracite Field where the two intergrade. (*Cf.* findings by David White, 1898–1899.) The disconformable Pottsville-Mauch Chunk contact has already been exemplified by the Wilkes-Barre sections. The transitional relations may be seen along the Schuylkill Valley starting from the south edge of Pottsville, central Schuylkill County:

	Thickness (Feet)
a. Pottsville conglomerate	
b. Transitional beds, intermingled conglomerate and red shale of Pottsville and Mauch Chunk types respectively	80
c. Mauch Chunk red beds	3300

FIGURE 1. EXPOSURE OF COARSE KNAPP CONGLOMERATE
On Wintergreen Run near Tally Ho, McKean County, showing large, ellipsoidal pebbles.

FIGURE 2. WETMORE CONGLOMERATE, TYPE LOCALITY
One-half mile south of Wetmore, McKean County, on R.R. Exceptionally pure sandstone and conglomerate showing cross-bedding.

KNAPP AND WETMORE CONGLOMERATES

FIGURE 1. CONTACT OF POCONO SANDSTONE AND UNDERLYING CATSKILL RED BEDS
South of Antrim, Tioga County. Note resemblance to channel-filling.

FIGURE 2. MISSISSIPPIAN-DEVONIAN CONTACT, MASSIVE POCONO SANDSTONE ON WEAK MOUNT PLEASANT RED SHALE
Fall Brook Valley, southeastern Tioga County.

MISSISSIPPIAN–DEVONIAN CONTACTS

LOWER LIMIT

In northeastern Pennsylvania the Devonian continental Catskill facies reaches 2000 to 3000 feet of alternating red and nonred (green to gray-green) units which are individually from 150 to several hundred feet thick. The highest, the Mount Pleasant red shale, has a maximum in northeastern counties of about 400 feet and directly underlies the gray Pocono formation. In common with the rest of the Catskill it carries the *Archaeopteris* flora, but, unlike the rest, does not pass westward into marine Devonian beds. It feathers out in northwestern Potter County, where it underlies marine Knapp rather than continental Pocono. One of the westernmost occurrences found is south of Kinney Corners in north-central Potter where 12 feet of the red beds remains.

Wherever contacts of the arenaceous Knapp or Pocono with the Mount Pleasant were observed in north-central counties, they resemble channel fillings in that the fairly massive sandstones or conglomerates of the Mississippian rest upon eroded, less-resistant Devonian red beds (Pl. 2, figs. 1, 2). In certain areas, not immediately related to this paper, there is evidence of an intersystemic transition. For a discussion of the Devonian-Mississippian relations in continental sequences in Pennsylvania, *see* Willard (1939).

Westward, beyond the limit of the Mount Pleasant red shale, the base of the marine Mississippian, the Knapp, and the highest marine Devonian, the Oswayo, are in contact, because the continental Elk Mountain which underlies the Mount Pleasant to the east has passed over into the marine Oswayo carrying *Camarotoechia alleghania* (Williams) and *Cyrtospirifer disjunctus* (Sowerby). The place of the Mount Pleasant is represented by a Devonian-Mississippian "break" among the marine beds. Relations were described by Caster (1934, p. 55, 106) who drew a minor disconformity at the top of the Oswayo. This statement the author has verified in the field, both with Caster and subsequently while working alone.

AGE OF MISSISSIPPIAN IN NORTHERN PENNSYLVANIA

The age of the Mississippian system in northern Pennsylvania is demonstrable. Caster's report (1934) makes the Knapp early Kinderhookian in age. Beneath the Knapp west of Potter County the Oswayo is late Devonian (upper Conewango). Upon the Knapp rests the early Pennsylvanian Olean. The Oswayo passes east into the Elk Mountain, the latter overlain by the red Mount Pleasant. Therefore, the Mount Pleasant is slightly younger than the Elk Mountain and the Oswayo, probably the youngest Devonian in Pennsylvania. Summarized, we have:

W.					E.
	Olean	Olean	Pottsville	Pottsville	
	—	—	—	Mauch Chunk	
	Knapp	Knapp	Pocono	Pocono	
	—	Mt. Pleasant	Mt. Pleasant	Mt. Pleasant	
	Oswayo	Oswayo	Elk Mountain	Elk Mountain	

If Pocono-Mount Pleasant relations imply synchroneity of the basal Pocono throughout, Pocono deposition spread across the northern part of the State in Kinderhook time. The interfingering of the highest Mauch Chunk with the Potts-

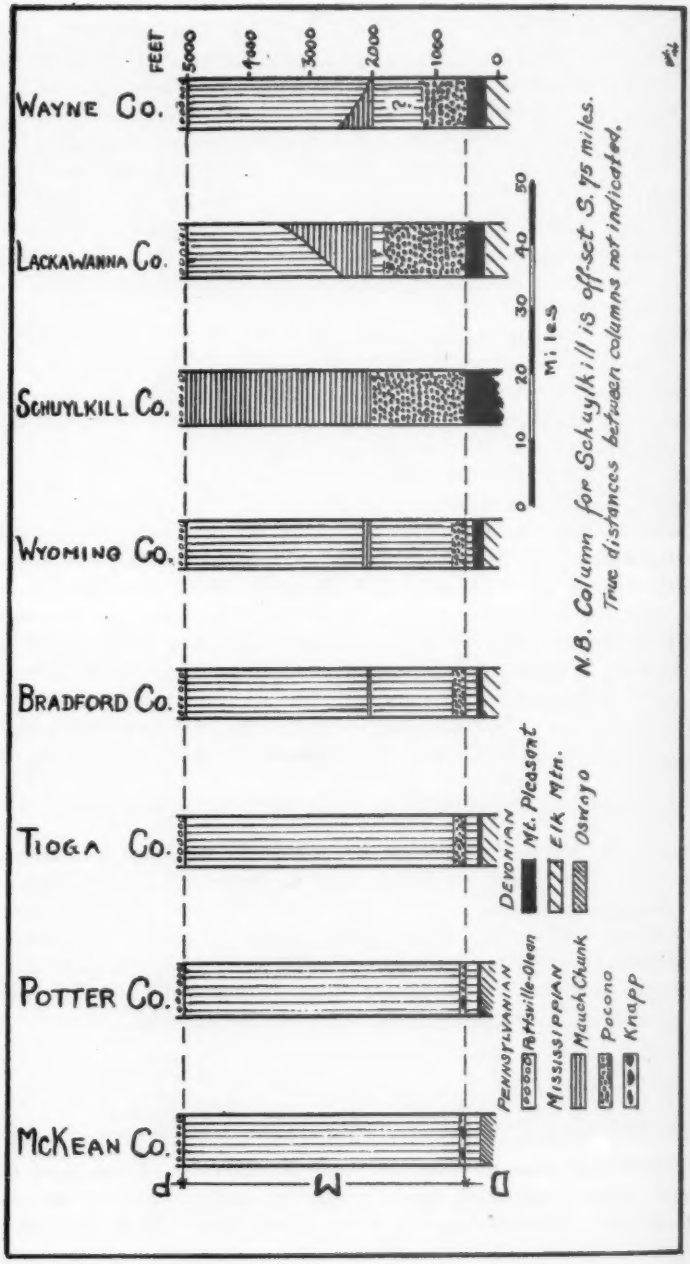

FIGURE 2.—*Mississippian relations in northern Pennsylvania*

ville in sections showing the maximum of red beds indicates that there, at least, Mauch Chunk deposition persisted to the close of Mississippian time. Elsewhere, the interval of Mauch Chunk and Pocono deposition was reduced. The Mauch Chunk drops out, and the Pocono thins and merges with the Knapp. Thus the Mississippian-Pennsylvanian gap increases from zero in the east to an interval running from approximately the close of Kinderhook time to the opening of the Pennsylvanian in the west.

MARINE-CONTINENTAL TRANSITION

The marine-continental transition of the Mississippian system in northern Pennsylvania can be observed in McKean and Potter counties. The Kushequa shale in the lower Knapp becomes sandstone indistinguishable lithologically from the rest of the formation; the Marvin Creek coquinite disappears among the flood of coarser clastics and the dying out eastward of marine life. Ellipsoidal-pebble conglomerates of the Knapp merge into spheroidal-pebble beds of the Pocono. These changes may be traced through by following a succession of sections from McKean County eastward.

A section was measured at East Kane a mile southeast of Kane in south-central McKean County, starting at the head of Willson Run and thence along the U. S. Highway 219 and in quarries:

	Thickness (Feet)	Thickness (Inches)
Olean float, none surely in place.		
Knapp, partly concealed.		
a. Brown sandstone, weathering brown, platy to flaggy, some shale and siltstone; thin lenses of ellipsoidal pebble conglomerate of milky quartz, no jasper; mud-chip layers; ferruginous concretions and ripple marks. Marine fossils, fucoids and fish fragments all present. Interval	140	
b. Continuing in quarry, sandstone	5	
c. Conglomerate, none in place	3	
d. Sandstone, brown, brown weathering, flaggy, chip-layers, fucoids, fish plates	22	
e. Sandstone, same as "b" but heavier bedded	4	
f. Fossiliferous zone		3–6
g. Sandstone similar to "e"	4	
h. Fossiliferous zone, coquinite with ellipsoidal, milky quartz pebbles scattered throughout		6
i. Base of quarry, water seeps, shale, gray, plus thin sandstone beds, weathers rusty	4	
j. Concealed interval	20–22	
k. Sandstone, flaggy, olive brown, weathers brown and includes some fine conglomerate with ellipsoidal pebbles. Many limonitic concretions and fucoids	11	
l. Coquinite		6
m. Sandstone, similar to "k", but heavier, lowest beds exposed		

Members "a" and "b" are probably parts of the same and represent the highest Knapp exposed here. The shaly member "i", may represent the Kushequa with more sandstone below or perhaps interbedded. The coquinites have the characteristics of the Marvin Creek.

In northeastern McKean County in the region north of Smethport and east of Bradford, the sequence based on several sections is generalized as follows:

FIGURE 2.—*Mississippian relations in northern Pennsylvania*

Knapp. Sandstone, brown, weathers gray, mud-chip layers, occasional conglomeratic bands of ellipsoidal pebbles; limonitic shells. Marine fossils plus fucoids resembling *Fucoides graphica* and the Silurian fossil *Arthrophycus*.

Kushequa. Platy to clayey shale, olive brown, weathers brown, some sandstone bands, some yellow, residual clay.

Marvin Creek. Changing from coquinite to fossiliferous sandstone resembling coquinite but noncalcareous, perhaps merely due to leaching.

A section illustrating the above more specifically was measured along the county road at Rixford, 8½ miles north of Smethport:

	Thickness (Feet)
a. Olean, float only.	
b. Knapp, upper part hidden, interval not measured; lower part exposed as conglomerate and pebbly sandstone, brown, weathers darker brown. Some ellipsoidal, some spherical pebbles all under ¼ inch diameter.....Exposed	8
c. Kushequa shale, weathers to clay. Five feet below top a thin, olive-gray sandstone with carbonized plant remains and ten feet below top a ferruginous band....min.	10
d. Oswayo sndstone.....exposed	55

Eastward in northwest Potter County, the Knapp is still fossiliferous, but spherical pebbles dominate in the conglomeratic beds. Occasional fossiliferous bands may mark the last expression of the Marvin Creek. Down the north slope of Clara Mountain to Clara in the northwestern corner of the County the following road section was obtained:

	Thickness (Feet)
a. Pottsville (or Olean) represented only by float rock, nothing in place.	
b. Knapp sandstone, top hidden. Minimum.....	97
c. Kushequa shale.....	35
d. Mount Pleasant red shale.....	15
e. Oswayo green, cross-bedded sandstone.	

The foregoing bears comparison with a section obtained on the county road, upgrade, south of Kinney Corner, north-central Potter County:

	Thickness (Feet)
a. Olean or Pottsville, float only, nothing surely in place, but confined to higher ground.	
b. Knapp. Upper part represented only by float, but lower in place as sandstone, brown to olive-brown, weathers gray, medium coarse texture, layers of mud chips. Maximum interval.....	135
c. Mount Pleasant red shale and soil coloration; maximum interval.....	12
d. Oswayo, greenish, cross-bedded sandstone.	

In this section there is no recognized Kushequa or Marvin Creek. The Knapp is essentially the sandstone lithology of that formation, though lacking pebbles. No Mississippian marine fossils were found east of here.

The sections in northern and northwestern Potter represent the easternmost marine Mississippian found. To the east and southeast the system is thought to be all continental. Since Knapp is applied to the marine facies, it is appropriate to use Pocono for the nonred continental Mississippian east of central Potter County.

In northwestern Potter County the Knapp is fairly typical, still marine, carries some ellipsoidal pebbles, but changes are apparent. Jasper pebbles are practically absent, and among the ellipsoidal pebbles is an ever-increasing proportion of spheroi-

dal ones. State Highway 44 south from Sweden Valley traverses forest land in south-central Potter County. In this area exposures of the Mississippian indicate no Mauch Chunk, but the Pocono is brown, gray-weathering sandstones with mud-chip layers, plant shreds, and limonitic deposits. Conglomerates appear to be lacking. Its Knapp-like lithology does not comport with the absence of marine fossils.

In central Tioga County at the fire tower 8 miles northwest of Wellsboro a quarry exposes part of the Pocono sandstone, flaggy, gray to olive brown, micaceous. It includes limonitic bands and layers of mud-chips, but also coaly pockets or matted plant fragments. Again, the lithology is Knapp-like, but lack of marine organisms places it in the Pocono. It is not far from here to northern Lycoming and southwestern Bradford counties where the northwestern limits of unquestioned Mauch Chunk lie, as indicated in previous sections. In the small coal field in northwestern Wyoming County an incompletely exposed sequence indicates approximately 65 feet of Mauch Chunk red beds resting on flaggy to massive Pocono sandstone that is gray or greenish gray, medium-textured, but without conglomerate or cross bedding.

MISSISSIPPIAN ENVIRONMENT

Conditions under which the Mississippian system in Pennsylvania formed can be only partially treated as the present paper does not cover the entire State. There is still much of southern and southwestern Pennsylvania to be fully studied. However, enough is known so that general conclusions for Pennsylvanian may be ventured to supplement data on the more completely studied northern regions.

With the exception of the Loyalhanna and Greenbrier limestones at or near the base of the Mauch Chunk, and of a single marine shale, the Riddlesburg, in the midst of the Pocono—all in southwestern Pennsylvania, the entire Mississippian through to the Anthracite Fields is considered continental. Thickness changes, textural variations, and distribution with respect to the marine Mississippian sequence in the northwest suggest that the provenance of the continental beds must have been to the southeast. From such a positive area, sediments were swept northwestward across lower ground toward the interior sea. There may have been more than one locus of maximum deposition. Except in the extreme southwestern quarter of the State the Mauch Chunk probably never reached the strand. The Pocono, conversely, extended northwestward to the sea and passed into the marine Knapp. At this passage one finds some indications of strand-line conditions.

It has sometimes been argued that the ellipsoidal pebbles of the Knapp were formed by wave shuttling in shallow water as contrasted with current-formed spheroidal pebbles of the Pocono, Olean, or Pottsville. Certainly, in Pennsylvania, the ellipsoidal pebbles are found in a marine, the others in a continental, sediment, whatever may have been the mechanical processes which shaped them. The Knapp conglomerates are discontinuous in areas in Potter, McKean, Elk, and Cameron counties. They are usually lenticular or fusiform bodies. An illustration lies 2 miles east-southeast of Kane in the woods along the southwest slope of Rocky Ridge where a 10-foot cliff of Knapp crops out. The rock is largely conglomerate plus sandstone; it is brown, weathering to light gray. The ellipsoidal pebbles average

half an inch long. The rock is noticeably cross bedded. Traced along the outcrop, it thins out and probably does not extend laterally more than half a mile. It is interpreted as a bar or beach. The conglomerate at Wetmore may have had such an origin. The distribution of the coquinites of the Marvin Creek may indicate near-shore conditions. That the Knapp was largely a shallow-water deposit is inferred from its coarseness, impurity, ripple marks, sudden textural changes, relatively large, thick-shelled fossils.

The rather abrupt termination eastward of the marine facies as indicated by the fossils is out of harmony with the lithology which does not change simultaneously. Although marine fossils were not discovered east of north-central Potter County, a typical Knapp lithology extends into central Tioga County, a distance of 35 to 40 miles farther. From Tioga east, the rock assumes Pocono lithology. The eastern Pocono is relatively purer sandstone and conglomerate than the Knapp. Possibly the nonmarine beds of Knapp lithology represent coastal plain deposits. Pebbles or conglomerates are few; the sandstone matrix is "dirty." This phase grades without pronounced lithologic variation into the marine facies.

One other item remains. Some of the Knapp conglomerates are fairly coarse. They are separated from equally coarse Pocono beds by scores of miles. The Knapp contains jasper pebbles unknown in the Pocono. It is hard to conceive of their having a common source. If the Knapp came from some other provenance than did the Pocono, almost the only possibility would be to the north. There appears to be an analogue in the Olean conglomerate of north-central Pennsylvania as contrasted with its correlative, the Pottsville of the Anthracite Fields.

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Presented before the Society, December 28, 1945.
Manuscript Received by the Secretary of the Society, January 7, 1946.
Published with Permission of the State Geologist of Pennsylvania.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 57, PP. 797-828, 8 FIGS. SEPTEMBER 1946

PETROGRAPHY AND RADIOACTIVITY OF FOUR PALEOZOIC MAGMA SERIES IN NEW HAMPSHIRE

BY M. P. BILLINGS AND N. B. KEEVIL

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ABSTRACT

The Ordovician (?), Silurian, and Devonian strata of New Hampshire are intruded by igneous rocks belonging to four magma series, the oldest of which is late Ordovician (?), the youngest of which is Mississippian (?). Each magma series consists of rocks ranging from gabbro, diorite, or quartz diorite to granite.

Although individual specimens from a rock type within a single magma series commonly show considerable range in radioactivity, the average values show a progressive increase in radioactivity toward the granitic end of the series, which is three to four times as radioactive as the gabbro-diorite end of the series. The reason for this increase toward the granitic end of the series is not always clear, but in the White Mountain magma series this appears to be due to an increase in the amount of allanite and probably zircon. This magma series is twice as radioactive as the other magma series and considerably more radioactive than similar rocks elsewhere in North America. It is suggested that the parental basaltic magma from which the White Mountain magma series was differentiated was more radioactive than the primary magmas from which the older magma series were derived.

INTRODUCTION

GENERAL STATEMENT

This investigation of the radioactivity of the intrusive rocks of New Hampshire is one phase of a larger project concerned with a similar study of the plutonic rocks of North America. New Hampshire is an unusually fertile area for special study because of the presence of four magma series, the oldest of which is late Ordovician (?), the youngest of which is Mississippian (?); each series contains a fairly complete sequence ranging from gabbro or diorite to granite. Thus, a rare opportunity is available to compare and contrast the radioactivity of four magma series, each with its own distinctive mineralogy, texture, structure, and mechanics of intrusion.

The methods of studying the radioactivity of rocks have been described elsewhere (Keevil and Grasham, 1943). It will suffice here to say that the results are expressed in terms of the number of alpha particles emitted per milligram of rock per hour. From this may be calculated, by multiplying by 2.25 (Keevil, 1943), the radiogenic heat in calories produced per gram of rock per million years.

MAGMA SERIES OF NEW HAMSPHIRE

A magma series may be defined as a group of comagmatic igneous rocks, evolved during a relatively short part of geologic time. Both intrusive and extrusive phases may be represented. The magma series of New Hampshire have been intruded into metasedimentary and metavolcanic rocks of Ordovician (?), Silurian, and

Devonian age (Fig. 1). The metamorphism of these rocks is low grade along the Connecticut River, but increases to middle grade 5 to 8 miles to the southeast, and still farther southeast is high grade (Billings, 1937, p. 470–472, 539–544).

Four magma series have been recognized in western and central New Hampshire (Billings, 1934). The distribution of these magma series is shown in Figure 1. The Highlandcroft magma series, of late Orodvician (?) age, is confined to three relatively small areas near the Connecticut River. The Oliverian magma series, which is middle Devonian (?), lies some 12 miles southeast of the Connecticut River. The late Devonian (?) New Hampshire magma series, syntectonic with the Acadian revolution, is extensively developed throughout the State. The Mississippian (?) White Mountain magma series occupies a north-south belt, extending from the northern limit of the map (Fig. 1) to the Lake Winnipesaukee region.

Although the characteristics of these magma series are well known to geologists conducting research in New Hampshire, and details are given in numerous areal reports, no comprehensive summary has yet appeared. Data for the White Mountain magma series have been assembled by R. W. Chapman and Williams (1935), and their conclusions on its evolution have been substantiated by more recent studies. Moreover, Quinn (1944) has compared and contrasted the New Hampshire and White Mountain magma series in the Winnipesaukee region. However, inasmuch as a general summary of the characteristics of the various magma series has not been published, it is desirable to present brief descriptions of each series in the present paper. In preparing this material, it was necessary to rely on existing data; new studies to rectify possible errors and deficiencies were impossible.

SOURCE OF SPECIMENS

The radioactivity of 135 specimens of intrusive rocks from New Hampshire was determined. The detailed data will be presented soon in Keevil's paper covering all of North America, and it is unnecessary to repeat them here. Many of the specimens came from the petrographic collections in the Mineralogical Museum at Harvard University, and they will be so designated under "Donor" in the tables to be published in the latter paper. Most of the other specimens came from collections still retained in Billing's office at Harvard University, and in the tables will be designated "M. P. Billings" in the column headed "Donor"; one specimen, 3221-NH-122, was donated by E. B. Sandell.

The areal distribution of the specimens is shown in Figure 2. A more uniform distribution over the State was impossible for several reasons. Many areas have not been studied, and consequently collections have not been made. Moreover, because several geologists were away from home during the war, specimens from several excellent collections were not available; this is notably true of the Mt. Cube, Mt. Chocorua, Claremont, and Newport quadrangles, and the northern half of the Mt. Washington quadrangle. A total of 13 specimens came from the Bellows Falls, Monadnock, Milford, and Concord quadrangles, which are beyond the limits of the area covered by Figure 1.

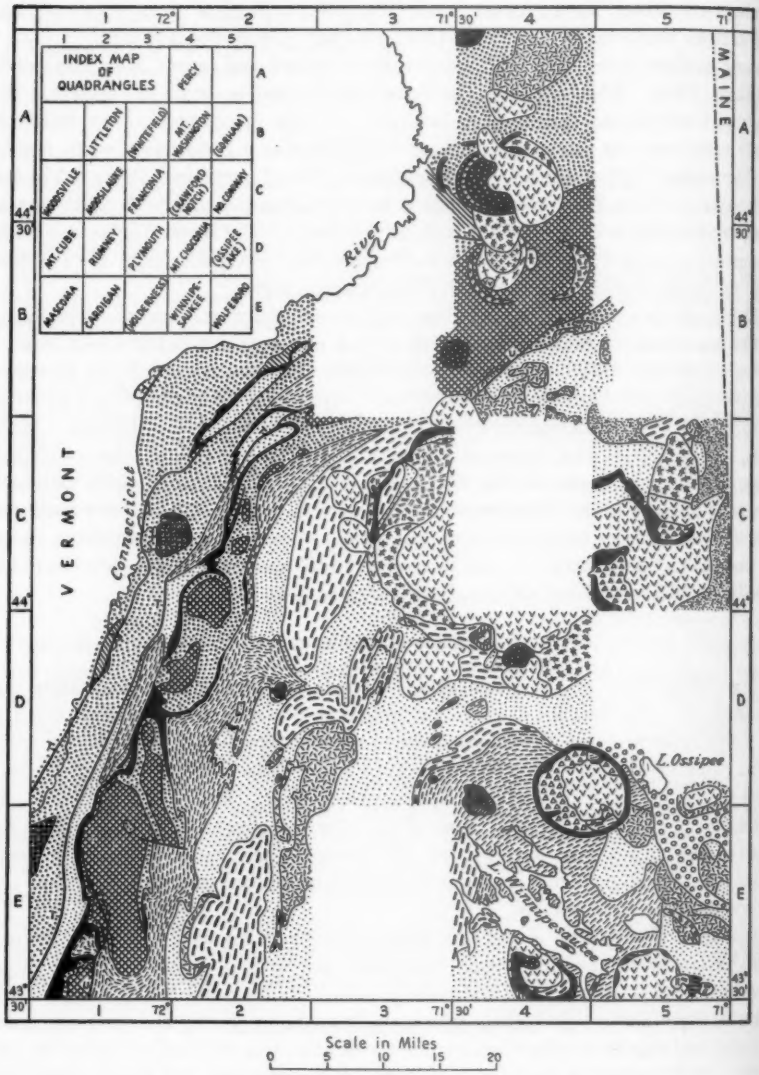
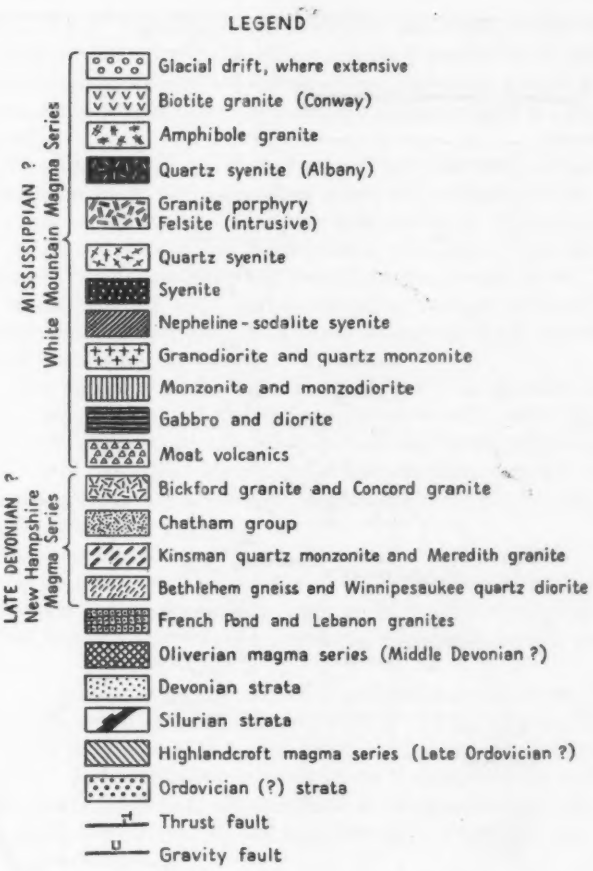


FIGURE 1.—*Geological map of central New Hampshire*



WHITE MOUNTAIN MAGMA SERIES

GENERAL STATEMENT

As shown in Figure 1, the Mississippian (?) White Mountain magma series occupies a north-south belt extending from the northern end of the map to south of Lake Winnipesaukee. There are also small bodies at the following localities shown in Figure 2: Pleasant Mtn., Maine; Pawtuckaway Mtns., New Hampshire; Mt. Ascutney, Vermont; and Monadnock Mtn., northeastern Vermont.

PETROGRAPHY

The White Mountain magma series consists of extrusive phases, known as the Moat volcanics, and intrusive phases, including both plutonic and dike rocks. This series is alkalic, in contrast to the three older subalkalic magma series. The plutonic rocks

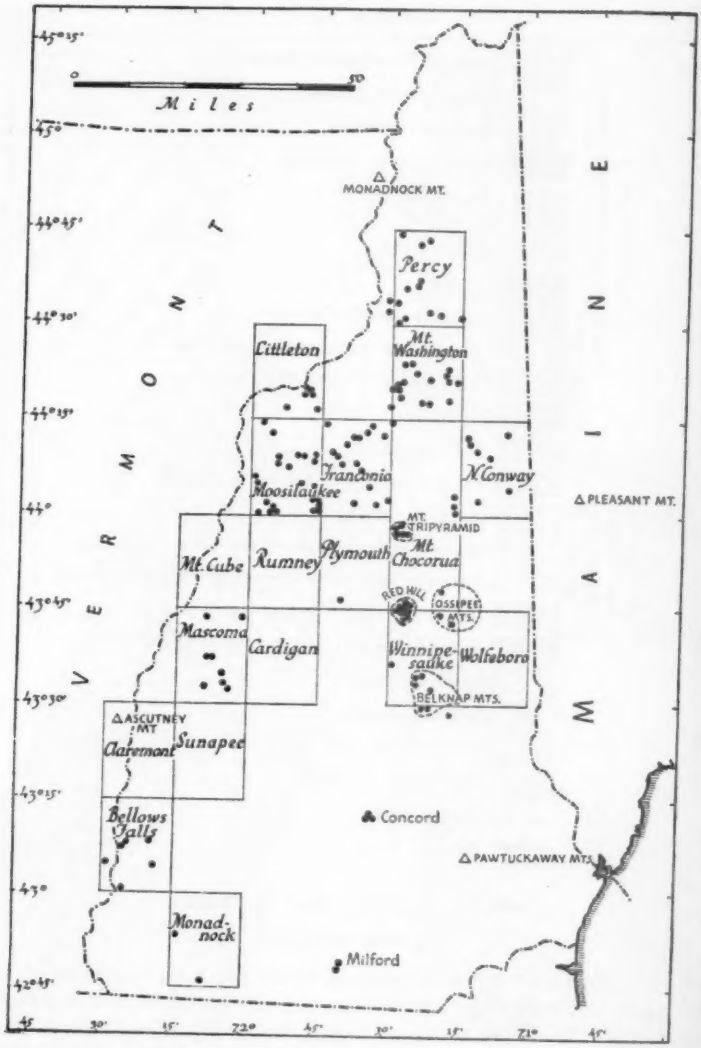


FIGURE 2.—*Index map giving location of specimens*

Map of New Hampshire and adjacent areas. Each dot represents one specimen. Quadrangles, mountains, and municipalities referred to in text are indicated.

are almost invariably massive, foliation and banding being limited to some of the gabbro and diorite. The rock bodies are typically (Fig. 1) ring-dikes and stocks (Billings, 1945).

The rocks have been classified as follows: gabbro, norite (hypersthene diorite),

diorite, quartz diorite, monzodiorite, granodiorite, monzonite, quartz monzonite, syenite, nepheline-sodalite syenite, analcime syenite (Pleasant Mountain, Maine), quartz syenite, granite porphyry, amphibole granite, riebeckite granite, hastingsite-biotite granite, and biotite granite. The order of intrusion, insofar as known, is from gabbro to granite.

Modes, representative averages of modes published elsewhere, are presented in Table 1. The reader should realize that these modes are averages and that values for individual specimens may depart considerably from the mean. A rough estimate of the area covered by each kind of rock is also given in this table. The area is given in per cent of the total area occupied by the White Mountain magma series. In all the modes given in Tables 1, 3, 5, and 7, potash feldspar is a term used to include orthoclase, microcline, and microperthite. The use of decimals for such minerals as apatite, zircon, and pyrite is explained below.

In some earlier papers (Billings, 1928; Kingsley, 1931) the syenites and quartz syenites were called nordmarkites, and this appellation is quite correct, if one wishes to employ names for alkalic rocks different from those used for subalkalic rocks.

The mineralogy of these rocks has been extensively studied, and more detailed information is available than for any magma series in the world (R. W. Chapman and Williams, 1935; Smith, 1940).

Microperthite is the characteristic potash feldspar of this magma series.

The olivine in the gabbro is a solid solution of 48 per cent forsterite and 52 per cent fayalite; it is absent in the intermediate rocks; in the granitic rocks it reappears in small quantities, but as a solid solution containing 90 per cent fayalite and only 10 per cent forsterite.

Pyroxene in the gabbro is a solid solution of 57 per cent diopside, 28 per cent hedenbergite, 12 per cent enstatite, and 3 per cent $FeSiO_3$. In the syenites, quartz syenites, and granites the pyroxene is a solid solution of 90 per cent hedenbergite, 10 per cent diopside. Some augite and "clinopyroxene" is reported from rocks ranging from norite to quartz monzonite. Hypersthene is found only in norite. Aegerine and aegerine-augite are confined to the nepheline-sodalite syenites and riebeckite granite.

Amphibole is "common hornblende" in the plagioclase-rich and intermediate rocks. Hastingsite and soda hornblende are the characteristic amphiboles in the syenite, quartz syenites, and granites. Riebeckite is common only in the riebeckite granites.

Biotite in the gabbro is intermediate between the iron and magnesia ends of the series but is lepidomelane (iron-rich biotite) in the granites.

It is apparent from the above description that all the ferromagnesium minerals show a striking, systematic increase in the iron-magnesia ratio progressing from the gabbro end of the series to the granitic end.

Muscovite, as Table 1 indicates, is rare in the White Mountain magma series.

Inasmuch as a great deal of the radioactivity of igneous rocks originates in the accessories (Keevil, Larsen, and Wank, 1944), a discussion of these minerals in the White Mountain magma series is necessary. As Table 1 indicates, the common accessories are opaques, apatite, zircon, sphene, fluorite, and allanite. Although quantitative data, based on heavy-mineral studies, are not available for New Hampshire,

TABLE 1.—*Average modes, White Mountain magma series*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Area*	tr	tr	tr	tr	1	tr	0.5	tr	9.2	0.3	†	5.3	5	9.4	9.2	3.0	2.0	55.0
Quartz		3		10	2	7	3	12	2			7	13	27	25	32	24	29
Plagioclase**	63_{60}	56_{45}	59_{45}	63_{46}	65_{25}	51_{42}	48_{30}	40_{30}	15_{15}		2_{27}	11_{25}	10_{20}	2_{10}	8_{20}	11_{10}	9_{20}	7_{12}
Potash feldspar	tr	4	tr	2	17	12	33	35	73	70	82	73	69	58	63	50	61	59
Olivine	10												tr	1	tr			
Pyroxene	14	16	10		4	5	1	1	2	2		1	1	2	tr	tr		
Amphibole	tr		6	9	5	13	5	6	7	8	6	7	7	6	4	6	3	tr
Biotite	5	7	17	15	5	8	6	tr	1	tr		1	tr	3	tr	1	3	5
Muscovite																		
Opaques: oxides	7	11	2		1		3	4	tr	tr	1	tr	tr		tr	tr	tr	tr
Opaques: sulphides	tr 0.16		tr 0.10		tr 0.06		tr 0.30	tr 0.16	tr 0.04	tr 0.08		tr			tr	tr		tr 0.08
Apatite	1 0.35	3 4.4	1 1.8		tr 0.28	tr	1 0.92	1 0.47	tr 0.40	tr 0.14	tr 0.33	tr 0.33	tr 0.21		tr 0.07	tr	tr	tr 0.14
Zircon			tr 0.03		tr	tr			tr	tr 0.07	tr 0.10	tr	tr 0.13		tr	tr	tr	tr 0.07
Sphene			tr		tr	tr	tr	tr		tr	2	tr	tr,			tr		tr
Fluorite													tr		tr	tr		tr
Allanite									tr		tr		tr			tr		tr
Epidote						tr		tr										
Chlorite			5		1	2												

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Epidote						tr		tr										
Chlorite			5		1	2												
Nepheline										14								
Sodalite										6								
Analcite											7							

* Rough estimate, given in per cent of total area occupied by this magma series.

† Found at Pleasant Mtn., Maine; not known in New Hampshire.

** The subscript indicates the average content of anorthite.

1. Gabbro. Olivine is solid solution consisting of 48% forsterite, 52% fayalite. Pyroxene is solid solution consisting of 57% diopside, 28% hedenbergite, 12% enstatite, 3% $FeSiO_3$. Biotite is intermediate in composition, with 15.52% FeO, 14.23% MgO.
2. Hypersthene diorite (norite). Pyroxene is 6% hypersthene, 10% augite.
3. Diorite. Pyroxene is augite, amphibole is hornblende.
4. Quartz diorite. Amphibole is hornblende. Accessories stated to be 1% of rock, but not listed.
5. Monzodiorite. Pyroxene is chiefly clinopyroxene, but there is a little hypersthene. Amphibole is hornblende. Biotite has 20.88% FeO, 2.33% Fe_2O_3, and 10.04% MgO.
6. Granodiorite. Pyroxene is solid solution consisting of 63% diopside, 37% hedenbergite. Amphibole is hornblende.
7. Monzonite. Pyroxene is clinopyroxene. Amphibole is hornblende. Biotite contains 12.74% FeO, 1.31% Fe_2O_3, and 16.75% MgO.
8. Quartz monzonite. Pyroxene is clinopyroxene. Amphibole is hornblende.
9. Syenite. Pyroxene is a solid solution, consisting of 90% hedenbergite, 10% diopside. Amphibole is hastingsite in some specimens, soda hornblende in others. Biotite has high FeO/MgO ratio.
10. Nepheline-sodalite syenite. Pyroxene is aegerine augite, amphibole is hastingsite.
11. Analcime syenite from Pleasant Mountain, Maine. Amphibole is apparently hastingsite.
12. Quartz syenite. Pyroxene is hedenbergite with small amount of diopside in solid solution. Amphibole is hastingsite in most cases, but on Mt. Tripyramid it is a pleochroic brown hornblende.
13. Quartz syenite, Albany type. Olivine is fayalite, pyroxene is hedenbergite, amphibole is hastingsite.
14. Granite porphyry. Olivine is fayalite, pyroxene is hedenbergite, amphibole is hastingsite.
15. Amphibole granite. Olivine is fayalite, pyroxene is hedenbergite, amphibole is hastingsite in some areas, soda hornblende in others.
16. Riebeckite granite. Amphibole is riebeckite. Astrophyllite is an accessory in some specimens.
17. Hastingsite-biotite granite. Biotite is iron-rich variety; that is, lepidomelane. Amphibole is hastingsite.
18. Biotite granite. Biotite is iron-rich variety, lepidomelane.

some information has been obtained at Pleasant Mountain, Maine, by Jenks (1934a). Moreover, as shown below, chemical analysis may be used to determine the amount of some of these minerals.

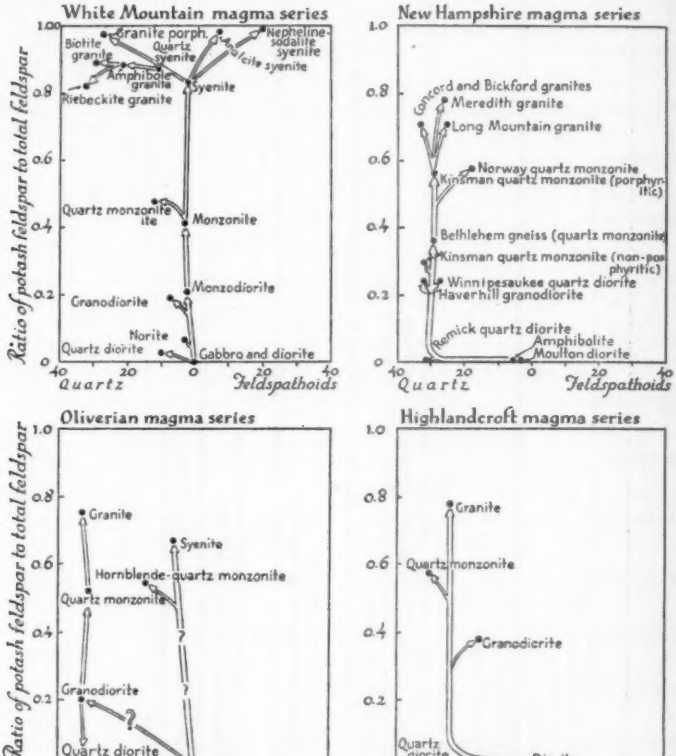


FIGURE 3.—*Graphic comparison of the four magma series*

Each magma series represented by a separate diagram. Each dot represents a rock type. Double lines with arrows represent inferred evolution, if rocks have been derived from mafic magma by fractional crystallization.

Some of the opaque minerals assume the importance of major constituents in the gabbro, norite, and diorite. Newhouse (1936), who has studied polished sections of 13 specimens of the White Mountain magma series, 8 from New Hampshire, 5 from adjacent Vermont, has identified the following opaque oxides: ilmenite; magnetite; and magnetite with exsolution lamellae of ilmenite, in some cases also containing spinel. Ilmenite dominates in the gabbro and diorite; magnetite, with or without exsolution lamellae of ilmenite, dominates in the nepheline-sodalite syenites, syenites,

and quartz syenites. Granites of this magma series were not studied. Sulphides are pyrrhotite, pyrite, chalcopyrite, and pentlandite, the last two apparently confined to the gabbro and diorite. In Table 1 the amount of sulphide present is listed twice. The upper figure is based on thin-section study and is qualitative only. The lower figure is based on calculations from chemical analyses. Although the calculation was based on the formula for pyrite, the figures undoubtedly give a fair idea of the amount of sulphide present.

The amount of apatite is shown in Table 1 in a similar way, the lower figure being based on the assumption that all the P_2O_5 shown by chemical analyses is confined to this mineral. In the gabbros, diorites, monzonites, and related rocks, apatite ranges from 0.28 to 4.4 per cent; in the nepheline and analcime syenites it is 0.40 to 0.47 per cent; and in the syenites, quartz syenites, and granites it is 0.07 to 0.33 per cent.

Zircon may be similarly calculated from the amount of ZrO_2 in the analyses. Unfortunately the necessary chemical data are available for less than one-third of the rocks, but they indicate that zircon ranges from 0.03 per cent to 0.13 per cent.

Sphene has been observed in many of the rocks. Jenks (1934a) states that on Pleasant Mountain, Maine, this mineral constitutes about 0.2 per cent of the syenite (nordmarkite). Although Jenks (1934b) lists 2 per cent sphene in the modes of the analcime syenite (Table 1, column 11 of the present paper) his study of the heavy minerals indicates only 0.6 per cent of this mineral.

Allanite is a characteristic accessory in the syenites, quartz syenites, and granites. Precise data on the amounts are lacking, but there is probably about 0.1 per cent in the granites.

Fluorite is characteristic of the quartz syenites and granites. It amounts to a small fraction of 1 per cent of these rocks.

EVOLUTION

R. W. Chapman and Williams (1935, p.527) concluded that the evolution of the White Mountain magma series from a basaltic magma was controlled by fractional crystallization, but the assimilation of older siliceous rocks played an important rôle.

In Figure 3 separate diagrams are given for each of the four magma series. The ordinate is the ratio of potash feldspar to total feldspar. On the abscissa the amount of quartz is indicated to the left of the vertical median line, the amount of feldspathoids to the right. Each dot represents a rock type as listed in the modes of Table 1. In the lower two-thirds of the diagram for the White Mountain magma series the dots are close to the median line, the amount of quartz averaging less than 10 per cent. Only at the top of the diagram do the dots spread out horizontally. This fact, coupled with all the other data about the magma series, indicates that from the gabbro to the syenite stage the evolving magma stayed close to the median line, and large amounts of quartz did not develop until after the syenite stage had been reached. In a few instances feldspathoids developed to give the nepheline-sodalite and analcime syenites. The lines with arrows indicate the inferred evolution. A consideration of the mechanics of this evolution is beyond the scope of this paper, but in general the scheme set forth by R. W. Chapman and Williams (1935) is acceptable.

RADIOACTIVITY

The radioactivities of the principal rock types in the White Mountain magma series are listed in Table 2, but unfortunately specimens of some types were unavailable. In the first column is the rock name, the second column gives the number of speci-

TABLE 2.—*Radioactivity of the White Mountain magma series*

Lithology	Number of specimens	Radioactivity: alpha particles emitted per milligram of rock per hour	
		RANGE	AVERAGE
MAJOR VARIETIES			
Gabbro	3	0.70–1.82	1.28 ±0.22
Norite (Hypersthene diorite)	1	0.56	0.56
Diorite	2	1.18–1.14	1.31 ±0.09
Monzodiorite	3	1.05–4.01	2.14 ±0.63
Syenite	8	0.79–5.03	2.29 ±0.34
Nepheline-sodalite syenite	1	1.17	1.17
Quartz syenite	4	1.60–3.36	2.46 ±0.29
Quartz syenite (Albany type)	5	2.69–5.12	3.49 ±0.31
Hastingsite-biotite granite	1	4.49	4.49
Hastingsite granite and soda-hornblende granite (Mt. Osceola type)	3	2.12–4.17	3.24 ±0.40
Riebeckite granite	2	2.34–3.01	2.67 ±0.22
Granite porphyry (Mt. Lafayette type)	3	4.15–5.04	4.55 ±0.06
Biotite granite (Conway type)	16	1.59–8.69	4.56 ±0.29
COMBINATIONS OF SOME OF ABOVE TYPES:			
Gabbro and norite	4	0.56–1.82	1.10 ±0.19
Syenite (including nepheline-sodalite syenite)	9	0.79–5.03	2.16 ±0.31
Quartz syenite	9	1.60–5.12	3.09 ±0.80
Amphibole granite	6	2.12–4.49	3.26 ±0.28
DIKE ROCKS			
Bostonite	1	1.75	1.75
Paisanite	1	5.61	5.61
Aplite	1	2.56	2.56
Nepheline syenite	1	0.99	0.99

mens tested, the third column gives the lowest and highest radioactivity, and the fourth column gives the average radioactivity. The probable error in each average is also given in the fourth column. It has been calculated according to the equation (Keevil, 1938):

$$p.e. = \pm \tfrac{1}{3} \sqrt{\frac{\Sigma(x - \bar{x})^2}{n\,(n-1)}}$$

where x is an observation, $\bar{x}$ is the average, and n is the number of observations.

The lowest average values are in the gabbro, norite, and diorite, with a general, but somewhat erratic increase to 4.56 in the biotite granite. The data are presented graphically in Figure 4. Although the abscissa could be either silica or, as Larsen (1938) has proposed, $\frac{1}{3}SiO_2 + K_2O–CaO–FeO–MgO$, neither is satisfactory when

applied to the Oliverian magma series, for reasons given later. Inasmuch as one purpose of the present investigation was to compare the four magma series, an abscissa satisfactory for all the magma series was necessary. In Figure 4 the central part of the abscissa, from diorite to syenite, is based on the ratio of potash feldspar to total

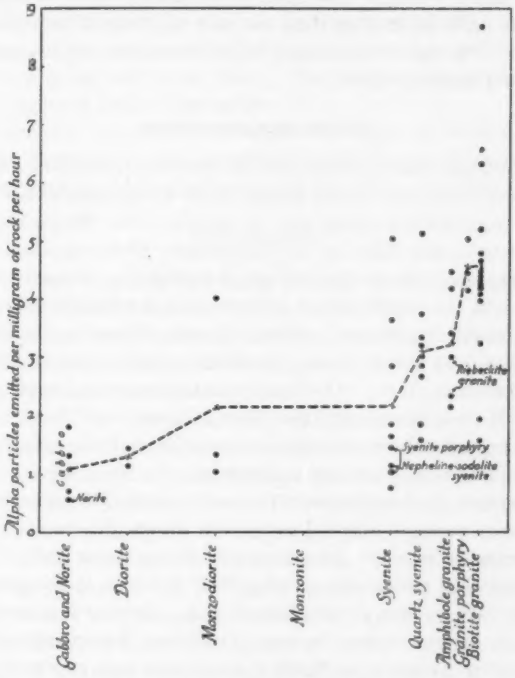


FIGURE 4.—*Radioactivity of White Mountain magma series*
Each dot represents one specimen. Each cross represents average for the rock type indicated in abscissa.

feldspar. Gabbro and norite have been placed to the left of diorite, and granites have been added to the right-hand end of the diagram. Quartz diorite has been placed a little to the right of diorite, and granodiorite, quartz monzonite, and quartz syenite have been placed to the right of their quartz-poor counterparts.

On the ordinate is plotted the radioactivity expressed in alpha particles emitted per milligram of rock per hour. Each small dot represents one specimen. Each cross is the average for a rock type.

It is clear that for each type of rock a great range in values occurs. In the biotite granite, for which 16 determinations were made, the lowest value is 1.59, whereas the highest value is 8.69. The average is 4.56. It is apparent, therefore, that a single determination for a type cannot be significant, and that a value for several specimens must be obtained in order to get a significant average.

Despite the great range shown by individual specimens, the average values show a progressive, although irregular, increase from the gabbro end of the series to the gran-

ite end. The average alpha particle emission for biotite granite is four times as great as the average value for gabbro.

The great range shown by individual specimens, despite the systematic variation shown by the averages, indicates that the source of the radioactivity is irregularly distributed through the rocks. The specimens studied, which usually contained 1 to 10 cubic inches, must be smaller than the unit that would be necessary to obtain uniform values. The size of such a unit is problematical, but it appears to be many times the size of a hand specimen.

SOURCE OF RADIOACTIVITY

In trying to find the reason for the four-fold increase in the radioactivity in progressing from gabbro to granite, we are presented with two possibilities: (1) The radioactivity of the responsible minerals may be constant, but the quantity of these minerals may increase several times; or (2) the quantity of the responsible minerals may be relatively constant, but the percentage of radioactive elements in them may increase several fold. A combination of these two possibilities should also be considered. The second hypothesis is difficult to test without separating samples of the same mineral—such as zircon—from the different rock types in the magma series; this is a time-consuming task. The first hypothesis may be tested if detailed modes are available. It should be recalled that Keevil, Larsen, and Wank (1944) discovered that in the Ayer granite the accessories accounted for half the radioactivity. Zircon, apatite, and epidote were especially radioactive. In the Lakeview tonalite of California, zircon, sphene, and apatite were the most radioactive minerals.

Whereas apatite averages only 0.2 per cent in the granitic end of the White Mountain magma series, it averages 2.2 per cent in the gabbroic end. The scanty data available suggest that zircon may average 0.09 per cent at the granitic end of the series, and only 0.03 per cent at the gabbroic end. Epidote is exceedingly rare in the White Mountain magma series. Sphene is common, but quantitative data are not available. Allanite, however, as Table 1 shows, has been recorded only in the syenites, quartz syenites, and granites; it is presumably the chief source of the high radioactivity of the granites.

Biotite, although relatively the most important mafic mineral in the biotite granite, is actually less abundant in these rocks than in gabbro, diorite, and monzonite. Potash feldspar is less common in the quartz syenites and granites than in the syenites, which have a relatively low radioactivity, hence it cannot be the explanation of high radioactivity of the granites and quartz syenites.

We conclude, therefore, that the increase in radioactivity in the granitic end of the White Mountain magma series is due primarily to the appearance of allanite, and secondarily to an increase in the amount of zircon.

NEW HAMPSHIRE MAGMA SERIES

GENERAL STATEMENT

The New Hampshire magma series is widely distributed throughout the State, extending from within 3 miles of the Connecticut River on the west (Fig. 1) to and across the Maine border on the east.

Many of the rocks of this subalkalic magma series are characterized by foliation and

granulation. The individual bodies are typically great concordant sheets or lenses, tens of miles long and thousands of feet thick, but the granites occur as irregular stocks. This magma series is syntectonic with the Acadian revolution. The oldest members—diorite and amphibolite—were intruded before the main deformation and have consequently undergone regional (hydrodynamothermal) metamorphism. The rocks of intermediate composition—quartz diorites, granodiorites, and quartz monzonites—are essentially synchronous with the folding and in some instances have had a secondary lineation imposed upon them. The youngest members—Concord and Bickford—have suffered little deformation.

Although, in general, the order of intrusion was from the dioritic to the granitic end of the series, there was some reversal of order, for the Winnipesaukee quartz diorite is younger than the Meredith granite (Quinn, 1944, p. 476–477).

PETROGRAPHY

The rocks have been classified as follows, average modes being given in Table 3: Moulton diorite, amphibolite, Remick quartz diorite, Winnipesaukee quartz diorite, Haverhill granodiorite, Bethlehem gneiss (quartz monzonite), Kinsman quartz monzonite, Norway quartz monzonite, Meredith granite, Long Mountain granite, and Concord granite (equivalent to Bickford granite).

The modes in Table 3 are averages; many specimens, some of which may deviate considerably from the mean, have been averaged for some of the columns. For example, although the Bethlehem gneiss averages quartz monzonite, it is very close to granodiorite. Moreover, some specimens of Bethlehem lack potash feldspar and are quartz diorite; exceptionally the Bethlehem gneiss is granite.

The Kinsman quartz monzonite in places is nonporphyritic; elsewhere it contains variable amounts of phenocrysts of potash feldspar 2 to 5 centimeters long. Where the phenocrysts become very abundant the rock is a granite, which has been called the Meredith granite in the Lake Winnipesaukee region.

The mineralogy of this magma series is strikingly different from that of the White Mountain magma series. Olivine and pyroxene are virtually absent. Amphibole is confined to the dioritic end of the series and is "common hornblende." Biotite is the chief mafic mineral and is distinctly dominant over hornblende in all rocks except diorite and amphibolite. Muscovite, so rare in the White Mountain magma series, is a major constituent in all the rocks, except diorite, amphibolite, and quartz diorite. Potash feldspar is typically, although not exclusively, orthoclase or microcline, rather than microperthite as in the White Mountain magma series. Quartz is a very important mineral in all but the diorites and amphibolites. Quartz is important in rocks in which the ratio of potash feldspar to total feldspar is small, whereas in the White Mountain magma series quartz in large quantities is confined to rocks with a high ratio of potash feldspar to total feldspar. Quinn (1944, p. 481) has also tabulated other features in which the two magma series differ.

As shown in Table 3, the principal accessories of the New Hampshire magma series are opaques, apatite, zircon, sphene, epidote, and garnet. The opaque oxides generally occur only as a trace but approximate 1 per cent in the dioritic end of the series. The large amount listed in the Norway quartz monzonite may be in error. Newhouse (1936) states that the Concord granite contains magnetite and ilmenite, the

TABLE 3.—*Average modes, New Hampshire magma series*

	1	2	3	4	5	6	7	8	9	10	11	12
Area*	1	1	2	23	tr	14	10	16	tr	8	3	18
Quartz	3	5	31	27	32	29	32	29	18	26	29	33
Plagioclase	36_{8}	33_{40}	52_{14}	48_{40}	45_{30}	33_{24}	36_{27}	23_{28}	25_{22}	13_{20}	15_{29}	17_{20}†
Potash feldspar				15	14	19	15	30	33	45	37	43
Olivine												
Pyroxene	tr											
Amphibole	27	56	1	tr		1						
Biotite	1	4	12	10	5	15	12	14	20	10	17	4
Muscovite	2	tr		tr	2	3	5	4	tr	5	2	3
Opaques: oxides	tr	1	1	tr	tr	tr		tr	3	tr	tr	tr
Opaques: sulphides		tr	tr 0.06			tr 0.10	tr 0.38	tr 0.20		tr		tr 0.54
Apatite		tr	tr	tr	tr	tr 0.28	tr 0.55	tr 0.26	1	tr	tr	tr
Zircon			tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Sphene	2	tr	tr	tr	tr	tr			tr			tr
Epidote	14	tr	3	tr	1	tr	tr				tr	
Chlorite	12	1		tr					tr			
Calcite	3	tr				tr					tr	
Garnet		tr	tr	tr		tr	tr	tr		1		

* Rough estimate, given in per cent of total area occupied by this magma. About 4 per cent of area is occupied by Chatham group, for which no averages are given.

† The subscript indicates the average content of anorthite.

1. Moulton diorite. Amphibole is hornblende, muscovite is sercite, and sphene is "leucoxene".
2. Amphibolite. Amphibole is hornblende.
3. Remick quartz diorite (called tonalite in Littleton-Moosilauke report).
4. Winnipesaukee quartz diorite. The ratio of potash feldspar to plagioclase is such that this average should be called a granodiorite. In the Mt. Chocorua quadrangle, where this map unit was first called quartz diorite, there is little potash feldspar. It is possible that some of the rocks in the Winnipesaukee quadrangle carrying considerable potash feldspar should not have been assigned to the Winnipesaukee quartz diorite, but they have been entered into this average.
5. Haverhill granodiorite.
6. Bethlehem gneiss. This average is a quartz monzonite, close to granodiorite.
7. Kinsman quartz monzonite, phase without large phenocrysts of potash feldspar.
8. Kinsman quartz monzonite, phase with large phenocrysts of potash feldspar.
9. Norway quartz monzonite. This mode may be unreliable.
10. Meredith granite. Although this is a common rock in New Hampshire, only one reliable mode is available.
11. Long Mountain granite.
12. Concord granite and Bickford granite.

latter in some instances containing exsolution lamellae of hematite. In this same rock he identified pyrite and chalcopyrite. The percentage of sulphide has been calculated and entered in Table 3 for those rocks for which chemical analyses are available; the method was the same as that employed for the White Mountain magma series. Apatite, usually recorded as a trace in thin sections, is estimated from chemical analyses to range from 0.26 to 0.55 per cent, but data are available for only three of the rock types. Zircon is recorded as a trace in many thin sections. Chemical analyses of the Remick quartz diorite and the Bethlehem gneiss record ZrO_2 as 0.00, implying that the amount of zircon is less than a hundredth of 1 per cent. Sphene and garnet are generally present as traces. Epidote is abundant in the Moulton diorite, but this rock, older than the main deformation, has been subjected to low-grade metamorphism. Allanite, so common in the more siliceous rocks of the White Mountain magma series, is exceedingly rare in the New Hampshire magma series.

Kruger (1941, p. 36) has concentrated the heavy minerals from six specimens of Bethlehem gneiss from the Moosilauke quadrangle and reports that they average the following percentages of the rock: biotite, 16.30; fluorapatite, 0.13; magnetite, 0.08; unidentified opaque, 0.08; chlorite, 0.02; zircon, 0.02; and small amounts of epidote, tourmaline, hornblende, monazite, and garnet.

EVOLUTION

The average modes of the New Hampshire magma series have been plotted in one of the diagrams in Figure 3. All the rocks, with the exception of diorite and amphibolite, lie far to the left of the median line, with quartz around 30 per cent. The contrast with the White Mountain magma series is apparent.

The field evidence that the various members of the New Hampshire magma series listed in Table 3 consolidated from magma is clear, at least within the area covered by Figure 1. Dikes and sills of all these rocks cut the older schists, and inclusions of the latter are found in the igneous rocks.

An advocate of fractional crystallization might suggest that the New Hampshire magma series has been derived from basalt, and that the early appearance of large quantities of quartz is a result of the simultaneous appearance of biotite, a silica-deficient mineral, as the sole ferromagnesian mineral (Bowen, 1928, p. 84). At the present stage of our knowledge this possibility cannot be denied.

Quinn (1944, p. 482) suggests that this magma series may represent melted sial. Still a third theory, for which there is some evidence, particularly for the Bethlehem gneiss and Meredith granite, is that granitized (migmatized) schists (Billings, 1941, p. 927–932) became sufficiently mobile at depth to move as magma and to intrude schists at higher levels.

RADIOACTIVITY

The radioactivity of the New Hampshire magma series is given in Table 4. The data are presented graphically in Figure 5. Individual specimens within a rock type deviate considerably from the average. Moreover, the lowest value for the granites (1.29) is less than the highest values for the diorites (1.73). Nevertheless, as the curve for the average values shows, the granitic end of the series is several times as

TABLE 4.—*Radioactivity of the New Hampshire magma series*

Lithology	Number of specimens	Radioactivity. Alpha particles emitted per milligram of rock per hour	
		RANGE	AVERAGE
Amphibolite	2	0.33–0.85	0.59 ±0.17
Moulton diorite	3	0.31–1.73	0.90 ±0.35
Remick quartz diorite	1	0.72	0.72
Winnipesaukee quartz diorite	2	0.15–0.85	0.50 ±0.23
Bethlehem gneiss (Quartz monzonite)	9	0.94–2.67	1.94 ±0.13
Kinsman quartz monzonite	7	0.99–2.31	1.71 ±0.14
Meredith granite	1	1.46	1.46
Long Mountain granite	2	2.30–3.19	2.74 ±0.29
Concord, Bickford, and related granites	15	1.29–4.55	2.60 ±0.13
Combinations of some of above types:			
Quartz diorite	3	0.15–0.85	0.57 ±0.15
Quartz monzonite	16	0.94–2.67	1.84 ±0.09
Granite	18	1.29–4.55	2.55 ±0.12
Chatham group*	4	0.80–1.56	1.12 ±0.11

* Not entered in averages because of inadequate petrographic data.

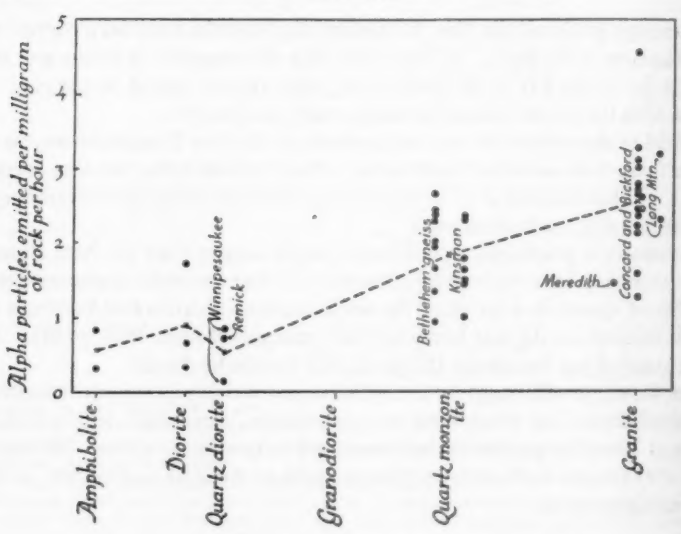


FIGURE 5.—*Radioactivity of New Hampshire magma series*

Each dot represents one specimen. Each cross represents average for the rock type indicated in the abscissa.

radioactive as the diorite-amphibolite end of the series. Comparison of Table 4 with Table 2, and Figure 5 with Figure 4, shows that the granites of the New Hampshire magma series are generally much less radioactive than the granites of the White Mountain magma series, and a similar relationship holds between the two series.

Quantitative data on the percentages of the accessory minerals in the New Hampshire magma series are insufficient to justify any attempt to explain why the granites are several times more radioactive than the diorite and amphibolite.

OLIVERIAN MAGMA SERIES

GENERAL STATEMENT

The Middle Devonian (?) Oliverian magma series is exposed principally in a belt, designated the Bronson Hill anticline, lying 10 to 15 miles east of the Connecticut River. This belt extends northeast and southwest beyond the limits of Figure 1. The French Pond and Lebanon granites (Fig. 1) originally assigned to the New Hampshire magma series (Billings, 1937) are now classified as members of the Oliverian magma series.

Many of the rocks of this subalkalic magma series are foliated, and most are granulated. The rocks are characteristically pink in contrast to the gray so typical of the New Hampshire magma series. The individual bodies, oval in plan, are 3 to 42 miles long and 1 to 9 miles wide. All the bodies in the Bronson Hill anticline possess a domical structure: a central igneous core, with outward-dipping foliation is overlain concordantly by outward-dipping Ordovician (?), Silurian and Devonian strata. Superficially, the individual bodies suggest laccoliths. Inasmuch as there is no evidence of floors each body may be the top of a "bottomless" stock, or all the bodies may belong to a single great intrusive sheet, initially horizontal, that has been buckled up into a series of domes (Billings, 1945). The French Pond and Lebanon granites, the latter described by C. A. Chapman (1939, p. 145–146, 158–159) and Kaiser (1938), are deformed stocks. The Oliverian magma series is older than the Acadian folding and is probably middle Devonian.

PETROGRAPHY

Throughout most of New Hampshire the lithology of this series is comparatively simple, and the rocks are classified as quartz diorite, granodiorite, quartz monzonite, and granite. Contacts between these various types are gradational, a fact emphasized on the quadrangle maps (Hadley, 1942; C. A. Chapman, 1939).

The average modes given in columns 1 to 5, Table 5, indicate the pertinent facts. In general, the mineralogy is not radically different from that of the New Hampshire magma series. Both series are characterized by abundance of quartz, rarity of pyroxene, and absence of olivine. Plagioclase in the Oliverian magma series is relatively uniform oligoclase; the anorthite content is about as high in granite as in quartz diorite, and the common tendency for plagioclase to become less calcic toward the granites is not observed. Biotite is the principal ferromagnesian mineral, and the dark minerals are no more abundant in the quartz diorites than in the granites. Muscovite is not as important as in the New Hampshire magma series. The potash feldspar is commonly microcline, whereas it is microperthite in the White Mountain magma series, and orthoclase is more common in the New Hampshire magma series.

In the Mt. Washington quadrangle (C. A. Chapman, Billings, R. W. Chapman, 1944) two unusual types appear. One, a hornblende-quartz monzonite (Table 5, column 6), which in places has large pink phenocrysts of potash feldspar, superficially

TABLE 5.—*Average modes, Oliverian magma series*

	1	2	3	4	5	6	7
Area*	10	30	25	15	2	5	13
Quartz	32	33	31	33	27	14	6
Plagioclase**	61_{25}	48_{22}	29_{24}	15_{20}	16_{18}	31_{23}	29_{21}
Potash feldspar	1	12	32	45	46	37	59
Olivine							
Pyroxene				tr			tr
Amphibole†	2	1		tr		12	3
Biotite	4	4	6	5	7	5	2
Muscovite	tr	tr	1	1	2		
Opaques: oxides	tr	1	tr	0.5	tr	tr	0.5
Opaques: sulphides		tr		tr 0.08	tr		
Apatite	tr	tr 0.07	tr	tr 0.05	tr	tr	tr
Zircon	tr	tr	tr 0.01	tr 0.01		tr 0.03	tr 0.06
Sphene	tr	tr	tr	tr	tr	1	tr
Epidote	tr	1	1	tr	1	tr	tr
Chlorite	tr	tr	tr	tr	1	tr	tr
Rutile	tr		tr	tr		tr	tr
Garnet	tr	tr	tr	tr			
Allanite	tr	tr	tr			tr	tr

* Rough estimate, given in per cent, total area occupied by this magma series being 100 per cent.
† Amphibole is always hornblende.
** The subscript indicates the average content of anorthite.

1. Quartz diorite.
2. Granodiorite.
3. Quartz monzonite.
4. Granite.
5. French Pond granite.
6. Hornblende-quartz monzonite.
7. Syenite.

resembles the Kinsman quartz monzonite and the Meredith granite. The second type is syenite (Table 5, column 7), composed of tabular pink crystals of potash feldspar that lie parallel to one another in many localities.

As Table 5 indicates, the accessories are opaques, apatite, zircon, sphene, epidote, garnet, rutile, and allanite. Comparatively few quantitative data are available. Magnetite, ranging on the average from a trace to 1 per cent, occurs as small octahedra 0.5 to 1 mm. in diamter. Chemical analyses of granodiorite and granite indicate, respectively, 0.07 and 0.05 per cent apatite. Unpublished spectrographic data for the Oliverian magma series in the Mt. Washington quadrangle indicate that zirconia is 0.01 per cent in quartz monzonite and granite, 0.02 per cent in hornblende-quartz monzonite, and 0.04 per cent in syenite; these figures indicate 0.01, 0.03, and 0.06 per cent of zircon, respectively in each of these three groups. Epidote, ranging from a trace to 1 per cent, is more abundant throughout the series as a whole than in the New Hampshire and White Mountain magma series.

EVOLUTION

The average modes have been plotted on one of the diagrams of Figure 3. Most of the rocks lie well to the left of the median line, the quartz content averaging about 30 per cent. In this respect, the Oliverian and New Hampshire magma series are alike. The syenite, which covers a large area in the Mt. Washington quadrangle, lies near the vertical median line.

C. A. Chapman (1939, p. 166–170) has suggested that most of the Oliverian magma series in the Mascoma quadrangle consolidated as granodiorite, much of which was later partially replaced by potash feldspar to produce quartz monzonite and granite. According to this hypothesis the series evolved from granodiorite through quartz monzonite to granite, but the process was replacement and not fractional crystallization. As Hadley (1942, p. 141) has suggested, the quartz diorite appears to represent a zone of mixed rocks between the granodiorite and the older Ammonoosuc volcanics. The parental granodiorite suggested by Chapman may have originated by melting, fractional crystallization, or some other process. Billings believes that the granite of the Mt. Washington quadrangle is not the result of replacement but consolidated from a granitic melt. In any case, as shown by the solid lines in Figure 3, the quartz monzonite and granite evolved from granodiorite, either through replacement or fractional crystallization. The quartz diorite is the result of assimilation. The syenite is well off the main line of descent and, if fractional crystallization was the principal evolutionary mechanism, must have followed a course similar to the syenites of the White Mountain magma series. The possible evolution of the Oliverian magma series from ancestral gabbro is shown in Fig. 3 by lines marked by queries.

RADIOACTIVITY

The radioactivity of the Oliverian magma series is listed in Table 6 and is presented graphically in Figure 6. The same generalizations may be made as for the younger magma series already described. Although individual specimens of a rock type show considerable range in radioactivity, the average values show a progressive increase

from the quartz diorites to the granites, the latter being 2½ times as radioactive as the former. The lone determination for syenite falls considerably below the curve suggested by the other rocks, which was also true for syenite in the White Mountain magma series.

TABLE 6.—*Radioactivity of the Oliverian magma series*

Lithology	Number of specimens	Radioactivity: alpha particles emitted per milligram of rock per hour	
		RANGE	AVERAGE
Quartz diorite	4	0.61–1.60	1.04 ±0.15
Granodiorite	6	0.59–3.07	1.35 ±0.25
Quartz monzonite	4	2.59–3.00	2.76 ±0.07
Granite	11	1.29–4.49	2.67 ±0.18
Syenite	1	1.77	1.77
Hornblende-quartz monzonite	2	1.29–2.44	1.86 ±0.39
Combinations of some of above types:			
Quartz monzonite	6	1.29–3.00	2.46 ±0.52

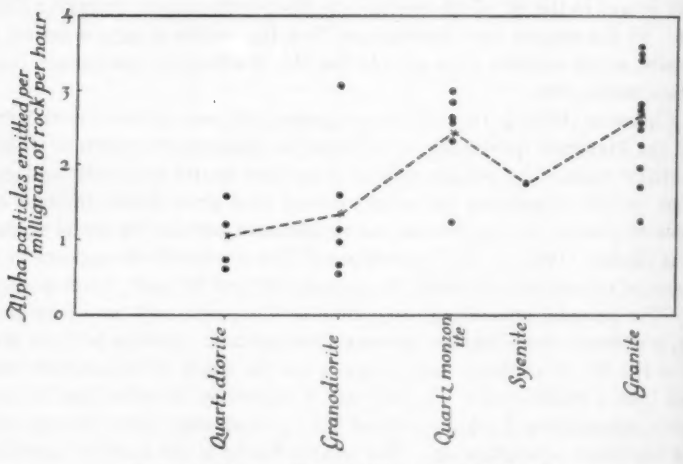


FIGURE 6.—*Radioactivity of Oliverian magma series*
Each dot represents one specimen. Each cross represents the average for the rock type indicated in the abscissa.

Quantitative data on the percentages of accessory minerals in the rocks of the Oliverian magma series are inadequate to justify any discussion of the cause of the high radioactivity of the granitic end of the series compared with the quartz diorite end.

HIGHLANDCROFT MAGMA SERIES

GENERAL STATEMENT

The late Ordovician (?) subalkaline Highlandcroft magma series occurs in three areas near the Connecticut River. In the Mt. Cube and Littleton quadrangles the

plutons are 5 to 7 miles long and 2 miles wide, but some of the contacts of the mass in the Percy quadrangle are beyond the limits of the area mapped. Little is known about the original shape of these bodies, because they have been considerably modified by the Acadian folding. They are truncated on the east by the Ammonoosuc thrust, and the body in the Littleton quadrangle is overlain unconformably by Silurian strata.

TABLE 7.—*Average modes, Highlandcroft magma series*

	1	2	3	4	5
Area*	5	30	30	30	5
Quartz	1	30	15	30	24
Plagioclase***	50_{10}	45_{10}	25_{10}	18_{10}	14_5
Potash feldspar			22	30	51
Olivine					
Pyroxene					
Amphibole†	20		8		
Biotite			7	9	4
Muscovite**		10	10	7	4
Opaques: oxides	2	2	tr	tr	
Opaques: sulphides					
Apatite			tr	tr	tr
Zircon				tr	tr
Sphene			tr	tr	tr
Epidote††	25	4	8	4	3
Chlorite		7	2	1	
Calcite	2	2	3	1	tr
Rutile					

* Rough estimate, given in per cent, total area occupied by this magma series being 100 per cent.
† Amphibole is always hornblende.
** Actually sericite.
†† Also zoisite.
*** The subscript indicates the average content of anorthite.
1. Diorite.
2. Quartz diorite.
3. Granodiorite. Biotite is pleochroic green, secondary mineral.
4. Quartz monzonite.
5. Granite.

PETROGRAPHY

The rocks have been classified as diorite, quartz diorite, granodiorite, quartz monzonite, and granite. The average modes, given in Table 7, reflect the fact that these rocks have undergone low-grade metamorphism. The original plagioclase, probably andesine, has been saussuritized to a mixture of albite-oligoclase, epidote, and sericite. The biotite, pleochroic in shades of green in thin section, is secondary. The hornblende and potash feldspar are primary minerals, but the chlorite and calcite are secondary. The accessories are listed in Table 7, but no supplementary data concerning them are available.

EVOLUTION

In one of the diagrams in Figure 3, the amount of quartz in this magma series has been plotted against the ratio of potash feldspar to total feldspar. The points occupy positions similar to those of the New Hampshire magma series, but somewhat nearer the median line—that is, in general the rocks of the Highlandcroft magma series have

TABLE 8.—*Radioactivity of the Highlandcroft magma series*

Lithology	Number of specimens	Radioactivity: alpha particles emitted per milligram of rock per hour	
		RANGE	AVERAGE
Diorite	1	0.59	0.59
Quartz diorite	1	0.58	0.58
Granodiorite	2	1.21–1.68	1.44 ±0.16

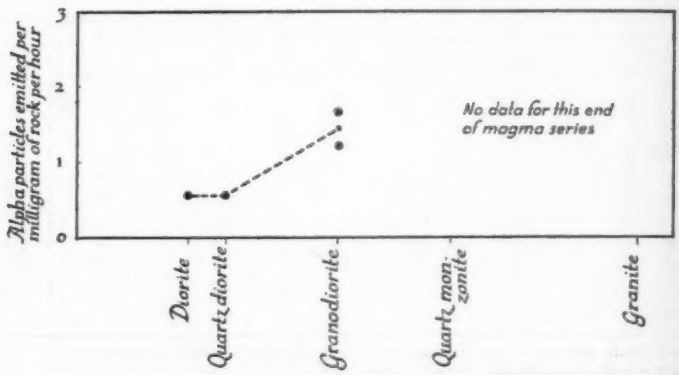


FIGURE 7.—*Radioactivity of Highlandcroft magma series*
Each dot represents average for one specimen. Asterisk is average value for granodiorite.

less quartz. A difference that this diagram does not bring out is that hornblende persists into the granodiorite stage in the Highlandcroft magma series, whereas biotite appears in the quartz diorite stage in the New Hampshire magma series.

The possible evolution of the magma series by fractional crystallization is indicated by the arrows in Figure 3.

RADIOACTIVITY

Data, available for only four specimens of the Highlandcroft magma series, are listed in Table 8 and are given graphically in Figure 7. The data indicate an increase in radioactivity from diorite to granodiorite. Specimens of quartz monzonite and granite were not available for study.

COMPARISON OF THE RADIOACTIVITY OF THE FOUR MAGMA SERIES

DATA

In Figure 8 the radioactivity curves for the four magma series have been assembled from Figures 4, 5, 6, and 7. It will be recalled from the previous discussion of the individual series that these curves are based on average values for each rock type. The curves are fairly complete except that data are unavilable for the granitic end

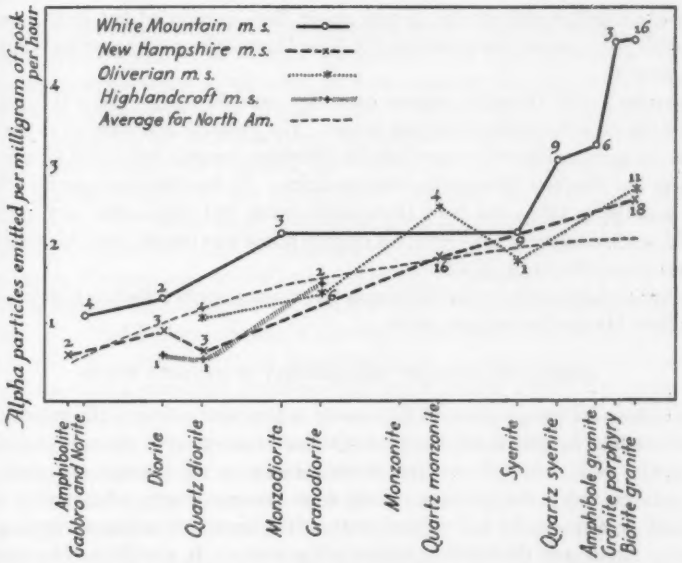


FIGURE 8.—*Comparative radioactivity of the four magma series*

Curves taken from Figures 3, 4, 5, and 6. Arabic numeral near each symbol gives number of specimens averaged to obtain value.

of the Highlandcroft magma series. A distinctive symbol, indicated in the legend, is used for each magma series. The numeral near each symbol shows the number of individual specimens averaged to obtain the value of the radioactivity. The reader can thus judge for himself how much emphasis should be placed on each point.

Smoother curves could, of course, be drawn, but, inasmuch as the data upon which they are based are averages, it seemed advisable to draw straight lines between points. Moreover, this method emphasizes the somewhat erratic character of the radioactivity. The reader can readily visualize what the smoother curves would look like.

The curves emphasize a point already brought out, the fact that the radioactivity increases from the gabbro-diorite to the granite end of each series, the increase being 4.15 times in the White Mountain magma series, 4.24 times in the New Hampshire magma series, and 2.57 times in the Oliverian magma series.

In both the White Mountain and Oliverian magma series the syenites produce a downward bend in the curve, indicating a radioactivity lower than the rest of the curve would suggest. Perhaps the curve for the New Hampshire magma series would show a similar depression if syenite were present.

The White Mountain magma series is considerably more radioactive than the other magma series. Its alpha activity averages 0.7 unit greater than that of the New Hampshire magma series. At the ends of the curves the White Mountain magma series is twice as radioactive as the New Hampshire magma series. The two curves are together only at the syenite stage, but, as pointed out in the preceding paragraph, this part of the curve for the New Hampshire magma series is not necessarily correct.

The curve for the Oliverian magma series lies, on the average, about 0.2 unit above that for the New Hampshire magma series. The greatest difference is at the quartz monzonite stage, where the curve for the Oliverian magma series is 0.62 unit above the curve for the New Hampshire magma series. At the syenite stage the Oliverian curve is actually below the New Hampshire curve, but this is not very significant, for only one specimen of the Oliverian magma series was tested, and the New Hampshire magma series lacks syenites.

The incomplete curve for the Highlandcroft magma series indicates that it is similar to the New Hampshire magma series.

REASON FOR GREATER RADIOACTIVITY OF GRANITIC ROCKS

The reasons for the progressive increase in radioactivity toward the granitic end of each of the four magma series has been discussed somewhat in the earlier sections of this paper. It is definitely not due to an increase in the content of potash. The most potassic rocks, the syenites, do not show the maximum radioactivity; in fact, they have an abnormally low radioactivity. The increased radioactivity is also not due to an increase in the biotite content of the rocks. In the White Mountain and New Hampshire magma series the radioactivity is inversely proportional to the content of biotite. Even in the Oliverian magma series the increase in biotite toward the granitic end of the series is slight. Apatite in many cases is one of the more radioactive minerals (Keevil, Larsen, and Wank, 1944). In the White Mountain magma series the content of apatite decreases as radioactivity increases. It is apparent, therefore, that the increase in radioactivity is associated with a decrease in the content of potash feldspar, biotite, and apatite.

In the White Mountain magma series it is well established that allanite, a radioactive mineral, appears in the granitic end of the series and is a conspicuous accessory. Moreover, there is an indication that the amount of zircon increases toward this end of the series. In the Oliverian magma series the few available data also indicate that the amount of apatite does not increase toward the granitic end of the series; moreover, the amount of zircon is apparently inversely proportional to the radioactivity. Therefore, except for the White Mountain magma series, data are insufficient to state whether the radioactive accessories increase in quantity toward the granitic end of the series.

It is obvious, however, that the radioactive chemical elements increase toward the

granitic end of the series. It may be that some of the minerals in the granitic end of the series contain a higher percentage of radioactive elements than the same minerals possess in the gabbroic end, due to a relatively higher concentration of radioactive elements in the later magma.

To solve this problem would involve extensive spectrographic investigation, separation of accessory minerals, and a study of their radioactivity.

GREATER RADIOACTIVITY OF THE WHITE MOUNTAINS MAGMA SERIES

The White Mountain magma series averages nearly twice as radioactive as the New Hampshire magma series. Inasmuch as the White Mountain magma series is the youngest magma series in the area, we must consider the quantitative effect of the decrease in radioactivity due to age. That is, if two equally radioactive magma series were intruded a billion years apart, the older one would be less radioactive at the present time because of its greater age. Actually, this is a minor factor in considering the magma series of New Hampshire. Inasmuch as the half-life period of uranium is 4.56×10^9 years, every 100 million years approximately 1 per cent of the uranium would disintegrate and the radioactivity would decrease by 1 per cent. At first the rate of disintegration would be nearly twice this amount. The White Mountain magma series is Mississippian (?), and the New Hampshire magma series is late Devonian (?). The difference in age is therefore at the most only a few tens of millions of years. We might expect the New Hampshire magma series to be a fraction of 1 per cent less radioactive than the White Mountain magma series, whereas actually the former is half as radioactive as the latter. The half-life period of thorium is 13×10^9 years; consequently, it would "run down" much more slowly than uranium.

The White Mountain magma series is more radioactive than the other series, either because it contains a greater quantity of radioactive minerals or because its minerals contain a higher proportion of radioactive elements. The granitic end of the White Mountain magma series contains a larger percentage of radioactive accessories than the other magma series. Allanite is common at the granitic end of the White Mountain magma series but is absent or exceedingly rare in the other magma series. Moreover, chemical analyses indicate that zircon is more abundant at the granitic end of the White Mountain magma series than in the corresponding rocks of the Oliverian magma series; chemical data are absent for the New Hampshire magma series. It appears, therefore, that the granitic end of the White Mountain magma series contains a higher percentage of radioactive minerals than the other magma series, and this is why it is more radioactive.

No data are available concerning the relative abundance of radioactive accessory minerals for the gabbro-diorite end of the New Hampshire magma series, and thus a comparison with the White Mountain magma series is impossible.

The fact that the gabbro-diorite end of the White Mountain magma series is nearly twice as radioactive as similar rocks in the New Hampshire magma series implies that the greater radioactivity of the White Mountain magma series has been inherited from the original gabbro magma from which it has been derived by fractional crystallization. This in turn implies that two different levels of the crust were tapped to give the two different magma series. This is in harmony with the con-

trasting tectonic behavior of the two magma series, for the New Hampshire magma series is syntectonic, whereas the White Mountain magma series is post-tectonic.

RADIOACTIVITY OF ROCK TYPES WITHOUT REGARD TO MAGMA SERIES

Table 9 lists the radioactivity of each rock type regardless of magma series. The number of specimens entering the averages are also shown. These averages show, of course, the same increase toward the granites as did the individual magma series, granite being more than three times as radioactive as the gabbro and diorite.

TABLE 9.—*Average radioactivity without regard to magma series*

Rock	Number of specimens in average	Radioactivity: alpha particles emitted per milligram of rock per hour	
		RANGE	AVERAGE
PLUTONIC ROCKS			
Gabbro	3	0.70–1.82	1.28 ±0.22
Norite (Hypersthene diorite)	1	0.56	0.56
Amphibolite	2	0.33–0.85	0.59 ±0.17
Diorite	6	0.31–1.73	0.98 ±0.15
Quartz diorite	8	0.15–1.60	0.81 ±0.10
Granodiorite	8	0.59–3.07	1.37 ±0.19
Monzodiorite	3	1.05–4.01	2.14 ±0.63
Quartz monzonite	22	0.94–3.00	2.01 ±0.08
Syenite	9	0.79–5.03	2.22 ±0.32
Nepheline-sodalite syenite	1	1.17	1.17
Quartz syenite	9	1.60–5.12	3.09 ±0.80
Granite	55	1.29–8.69	3.36 ±0.12
DIKE ROCKS			
Bostonite	1	1.75	1.75
Paisanite	1	5.61	5.61
Aplite	1	2.56	2.56
Nepheline syenite	1	0.99	0.99
Total	131		

4 specimens of Chatham group not included because of inadequate petrographic data.

AVERAGE RADIOACTIVITY OF INTRUSIVE ROCKS IN NEW HAMPSHIRE

The average of the 135 specimens, each specimen equally weighted, is 2.44 alpha particles per milligram of rock per hour. In a second average each rock type was weighted according to the area it covers. Rough estimates of the area underlain by each rock type in each of the four magma series have been listed in Tables 1, 3, 5, and 7. For each magma series the area occupied by a rock type is given as a per cent of the total area occupied by that magma series. The White Mountain magma series is estimated to occupy 31.5 per cent of the plutonic area of Figure 1, the New Hamp-

shire magma series occupies 42 per cent, the Oliverian magma series covers 25 per cent, and the Highlandcroft magma series occupies 1.5 per cent. The average radioactivity, weighted by area, for the terrain covered by Figure 1, is 2.45 alpha particles per milligram of rock per hour. This is almost identical with the average obtained merely by averaging the 135 specimens without regard to area. At first glance this agreement might seem to be fortuitous, but it is primarily due to the fact that the number of specimens studied for each rock type was roughly proportional to the area covered by that rock. Many specimens of rock types that cover large areas were studied, whereas comparatively few specimens of rock types covering small areas were investigated. There were a few exceptions.

TABLE 10.—*Average amounts of uranium and thorium in New Hampshire rocks in weight per cent**

	Uranium	Thorium
Gabbro	0.00020	0.00065
Norite	0.00009	0.00028
Amphibolite	0.00009	0.00030
Diorite	0.00015	0.00050
Quartz diorite	0.00012	0.00041
Granodiorite	0.00021	0.00070
Monzodiorite	0.00033	0.00109
Quartz monzonite	0.00031	0.00102
Syenite	0.00034	0.00113
Nepheline-sodalite syenite	0.00018	0.00059
Quartz syenite	0.00048	0.00157
Granite	0.00052	0.00170
Average	0.00038	0.00124
Lowest value	0.00002	0.00008
Highest value	0.00134	0.00442

* Based on the assumption that Th/U = 3.3. Although this ratio shows considerable range, the values are concentrated around 3.3 to such an extent that the error in the values given for U and Th would generally not exceed 25 per cent.

COMPARISON WITH OTHER AREAS IN NORTH AMERICA

One of the curves in Figure 8 is based on averages for several thousand igneous rocks from all of North America. It is apparent that the curve for the New Hampshire magma series lies close to the North American average. The incomplete data for the Highlandcroft magma series suggest that these rocks are also close to the average for the continent. The Oliverian magma series lies somewhat above the North American average. The White Mountain magma series, however, is twice as radioactive as the average igneous rock elsewhere in North America.

QUANTITY OF URANIUM AND THORIUM

The amount of uranium and thorium in rocks may be calculated from the alpha activity if the following assumptions are correct: (a) all the alpha particles emitted are derived from either the uranium series or the thorium series; (b) the ratio of tho-

rium to uranium is 3:3; (c) both uranium and thorium are in equilibrium with all members of their series. The equations are:

$$U = 1.540 \times 10^{-6}\alpha \quad (1)$$
$$Th = 3.3\ U \quad (2)$$

where U = uranium in grams per gram of rock
Th = thorium in grams per gram of rock
α = number of alpha particles emitted per milligram of rock per hour.

In order to calculate the amounts of uranium and thorium in weight per cent, the factor 10^{-4} is used instead of 10^{-6}. The data are given in Table 10, where the average amount of uranium and thorium for each rock type have been calculated from the average alpha activity as given in the last column of Table 9.

CONCLUSIONS

Specimens obtained from a single rock type, such as the biotite granite (Conway granite) or the Kinsman quartz monzonite, show considerable range in radioactivity. In extreme cases the difference between the most radioactive and the least radioactive specimens from a rock type is five fold, and on the average is two to three fold. It is apparent, therefore, that a single determination for a rock type is not significant, and ordinarily several determinations of the radioactivity should be made.

Average values for each rock type show that there is a progressive, although somewhat erratic, increase in radioactivity from the gabbro end of each magma series to the granitic end, the latter being three to four times as radioactive as the former.

The reason for this increase in radioactivity toward the granitic end of the series is not always clear. It is not associated, as some results in other areas suggest, with an increase in potash feldspar, biotite, or apatite. In the White Mountain magma series the radioactive minerals, especially allanite and probably zircon, increase in quantity toward the granitic end of the series. In the other magma series no conclusive evidence was found for an increase in the quantity of the radioactive minerals. It is possible, of course, that the radioactive minerals are not more abundant in the granitic rocks, but that the radioactive elements in these minerals are more abundant because of the increased concentration of radioactive elements in the magma at the time these minerals separated.

The alkalic White Mountain magma series is twice as radioactive as the other magma series. Paradoxically, however, the most alkalic rocks within this series—nepheline-sodalite syenite and riebeckite granite—are relatively low in radioactivity; lower than usual for syenitic rocks. Apparently the ancestral magma from which this series was derived was more radioactive than the magma from which the older magma series were derived. It is possible that a different layer of the crust was tapped during the evolution of the White Mountain magma series from that tapped during the eruption of the older magma series.

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HARVARD UNIVERSITY, CAMBRIDGE, MASS.
UNIVERSITY OF TORONTO, TORONTO, CANADA.
MANUSCRIPT RECEIVED BY THE SECRETARY OF THE SOCIETY FEBRUARY 25, 1946.
PROJECT GRANT 420/S/42.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 57, PP. 829-908, 3 PLS., 7 FIGS. SEPTEMBER 1946

NEW ALBANY SHALE

BY GUY CAMPBELL

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ABSTRACT

The New Albany shale in Indiana consists of the Devonian Blocher and Blackiston formations (90 feet thick) and the Mississippian Sanderson, Underwood, and Henryville formations (11 feet thick). This classification is based on floral and faunal content. The Underwood contains a Hamburg oölite fauna. These divisions continue through Kentucky, Ohio, and Tennessee. In eastern Kentucky the Trousdale,

a correlate of the Blocher, is underlain by the Tully Portwood formation, which contains three coeval facies; the Underwood and Henryville are replaced by the Bedford and Sunbury. In Ohio the Blackiston was contemporaneous with the Chagrin, and the Sanderson is equivalent to the Cleveland as restricted. The Olentangy shale is basal Blackiston and Upper Devonian in age. The Chattanooga in central Tennessee contains equivalents of all the Indiana New Albany divisions. New names are proposed for some of the Chattanooga beds. The Hardin sandstone is basal Devonian; the Mississippian basal bed is the Bransford sandstone. Beds classed as Maury occur in the Chattanooga and as basal New Providence and Fort Payne. The New Providence and Fort Payne overlie the Chattanooga disconformably. The Blackiston and Sanderson are represented in Alabama.

INTRODUCTION

GENERAL STATEMENT

The New Albany shale in Indiana and Kentucky, the black shales in Ohio, and the Chattanooga shale in Tennessee are parts of a continuous terrane of black carbonaceous shale deposited in an interior sea that extended from New York to Oklahoma and from Canada to Alabama, during a period of black-shale environment that probably was continuous from Tully to Kinderhook time. It is probable that black-shale deposition was not absent from the entire interior sea at any time during the New Albany period, or at least was not entirely replaced by any other type of sediment.

This terrane of shale, so conspicuous by contrast in color and character of sediments to adjacent strata, has frustrated attempts to reduce it successfully to conformity with the standard Devonian and Mississippian column. The paucity of fossils has been discouraging, and the uniformity in the character of sediments has been tantalizing, but nevertheless misleading, to stratigraphers. However, the reputed uniformity is more real over hundreds of miles horizontally than in 100 feet vertically. The black-shale problem has had separate study in the different States, and long-range correlations have been made, some of which were little more than assumptions. The strata of Kentucky have been stretched and squeezed and whittled on three corners to make them conform to the stratigraphic boundaries determined in the neighboring States.

The boundaries of the interior sea in New Albany time may be roughly located at the shores of the old land Appalachia in the east, and of Ozarkia in the west. The New Albany black muds were formed off shore from, and contiguous to, the Upper Devonian delta in the east, and in part contemporaneously with Kinderhook strata in the west.

In the midst of the New Albany sea stood the Cincinnati geanticline, which extended through the center of Ohio, Kentucky, and Tennessee. It had little effect on the migration of species but was more or less a barrier to the spread of sediments at different times and places, and its difference in relief, with the aid of a rising or falling sea level, at times provided islands, peninsulas, or submerged ridges with flanking sediments, whose strand character and enclosed animal and plant remains break the monotony of the great mass of black shale and reveal glimpses of the stratigraphic history of the New Albany shale.

The belt of outcrop under study extends from Lake Erie along the eastern flank, and from north-central Indiana along the western flank, of the Cincinnati arch to central Kentucky, thence along the crest of the arch to central Tennessee, where it divides and encircles the Central Basin along the Highland Rim, and unites again before extending into Alabama and Mississippi.

This paper gives the results of detailed tracing of the New Albany for 450 miles through Indiana, Ohio, Kentucky, and Tennessee, supplemented by a study of the reports of other geologists.

The outcrops cut across near-shore sediments, which supply a great part of the evidence on which the conclusions are based. It must be kept in mind, however, that the shores bordering the Cincinnati geanticline are secondary and are not the boundaries of the New Albany sea, hence do not mark the limits of the sediments that swept across the sea in a predominantly eastward or westward direction.

The stratigraphy of the New Albany is shown to best advantage by uniting Indiana and west-central Kentucky, west of the Cincinnati geanticline; Ohio and east-central Kentucky, east of the geanticline; and south-central Kentucky and Tennessee.

LITHOLOGIC CHARACTER

The New Albany shale is largely black and carbonaceous, but lenses of sandstone, lenses and concretions of lime, brown shale filled with *Sporangites*, and gray argillaceous shale occur at different horizons. The normal appearance of the different facies is seen only in fresh material, or in the presence of moisture; when subjected to weathering and while dry a gray film and collections of detritus cover the surface of an outcrop and, on casual observation, give rise to the statements that the New Albany is uniform in constitution throughout and over large areas.

Core analysis (Reeves, 1923) of the New Albany shale in the New Albany, Indiana, area shows the content of certain constituents in the different divisions of the New Albany (Table 1).

FISSILITY

Marked fissility is an outstanding character of the shale and varies indirectly with argillaceous or lime content. The fissile character is not made evident primarily by the tendency to split into thin layers, but by the composition of the shale which preserves the laminae intact after the division has been induced by weathering. The laminae are thinnest at horizons where the amount of fixed carbon and sulphur is greatest. These constituents apparently "temper" the laminae so that they withstand weathering beyond the stage that produces them. The overlying New Providence shale is as thinly fissile as the New Albany, but the laminae are so fragile and the stage of weathering that produces the cleavage is so near the stage that leads to deterioration of the laminae that it is difficult to secure specimens for study.

JOINTS

In the vicinity of New Albany, Indiana, outcrops of the New Albany shale are especially favorable for the study of joints, so characteristic of carbonaceous shales. In a

total thickness of 100 feet, 20 systems of joints have been studied and plotted. Reeves' (1922) claim of joints of 70 feet or more in vertical extent in the New Albany is erroneous.

In the New Albany in Indiana each system consists of a set with numerous joints

TABLE 1.—*Core analysis of New Albany shale*

		Ash	Sulphur	Fixed carbon	Oil (gallons)
New Albany shale (as a whole)	average	83.27	2.66	1.11	8.58
	maximum	89.23	5.86	6.35	13.20
	minimum	74.30	0.97	0.37	1.90
Sanderson	average	76.57	3.73	3.63	12.10
	maximum	78.21	5.83	6.35	13.20
	minimum	74.30	1.93	1.37	11.00
Upper Blackiston (black shale)		78.44	4.86	1.34	12.30
Lower Blackiston					
(black shale)		87.34	2.04	0.53	5.60
(gray shale)		86.43	1.98	0.37	6.09
Blocher (average)		86.65	1.74	1.05	8.80

running in an easterly direction and another set with fewer joints at almost right angles. In the former set the individual joints average about 5°–8° from east and west, but often vary from 10°–20°. The spaces between the joints may vary from a few inches in one system to as many feet in an adjacent system. The lateral extent of the joints has not been determined as no outcrops paralleling the jointing for more than a few hundred yards have been discovered. Adjacent joints in a set are seldom parallel; and when two converge, one pinches out. It is probable that some joints extend for great distances.

The character of the joints is illustrated by the following sets which occur near the bottom of the New Albany:

4. N.80°–70°E., spaced 6 to 22 feet, vertical range 15 feet;
3. N.85°–78°E., spaced 3½ to 6 feet, vertical range 4½ feet;
Disconformity. New fauna.
2. N.85°–82°E., spaced 1 to 7 feet, vertical range 3 feet;
1. N.82°–80°E., spaced 2 to 2½ feet, vertical range 6 feet.

Bedding planes separate these systems of joints, and between Nos. 2 and 3 there is a disconformity followed by a new fauna. Higher in the New Albany at one locality 22 joints spaced 6 to 22 feet occur within 100 yards. Gray-shale layers within beds of jointed black shale have no joints, but slicken-sides and massive cone-in-cone have been observed.

The following observations apply to the New Albany shale in all areas: (1) a change of lithology or a change of fossils is accompanied by a change of joints, (2) a change

of joints may or may not be accompanied by a change of lithology or fossils, (3) within the vertical range of a major system of joints, beds may contain one or more minor systems with smaller vertical limits, and (4) formational boundaries never occur within a system of joints.

The bedding planes in black shales are usually obscured by the planes of fissility and concealed by detritus, and a section many feet thick usually appears to be one continuous bed. Observation of the joints enables one to locate the bedding planes and thus divide the outcrop into units for study. Joints are usually given attention with emphasis on their probable cause, and their aid to stratigraphy has been neglected. In the present work joints have been valuable aids.

The boundaries of the major divisions of the New Albany in the type area in Indiana, and correlative divisions in other States, are indicated by changes in the systems of joints. The conditions that determined the boundaries of these systems must have been the same in all areas. Crustal movements and volume changes are given as causes of joints; the former would vary as to force and direction in different areas and would be indefinite as to time; the latter would be more uniform in results in different areas, and the time would be nearer that of deposition. It seems likely that many joints in the New Albany are due to shrinkage of sediments, and the different systems of joints may imply intervals of deposition separated by intervals of nondeposition and shrinkage, thus producing separate systems with different time values. The entire Upper Devonian of the east is represented in a part of the New Albany, but many of the changes evident in the east are not revealed in the New Albany unless they are represented in some of the units with distinct systems of joints.

PREVIOUS CLASSIFICATIONS

The New Albany early attracted the attention of geologists, and attempts were made to determine its affinities with the shales of New York. The early history of the stratigraphy of the New Albany is reviewed by Cumings (1922). Correlations on fossil evidence have been few. The Rockford limestone, overlying the New Albany, was assigned to the Kinderhook, thus providing an age limit for the New Albany. Fossils collected at Lexington, Indiana, by Borden (1875) and identified by Whitfield (1875, p. 179–182) determined the Genesee age of the lower 10 feet of the New Albany. Kindle (1900), on the evidence of fossils and character of shale at Delphi, northern Indiana, recognized the Portage age of part of the New Albany. Ulrich (1911) assigned a Mississippian age to all of the New Albany except the lower few feet. Butts (1915, p. 134) preferred "not to take a decided stand on the question of the age of the upper 90 feet of the New Albany, although strongly inclined to maintain its Upper Devonian age." Cumings (1922, p. 474) "inclined to the opinion that the New Albany shale in Indiana is Upper Devonian (Senecan?) throughout." Huddle (1933) collected fossils from near the top of the New Albany at Rockford, Indiana, which he identified as Devonian species, and decided that the New Albany was Devonian throughout; later (1934) he presented overlapping Devonian and Mississippian evidence on its age, with the final conclusion that the upper 5 feet may be Mississippian. Savage (1930), after a study of the New Albany shale in Kentucky,

classified it as not younger than Genesee in age. Stockdale (1939) assigned the upper 5 feet of the New Albany to the Mississippian on the evidence of Huddle's findings and on a misconception of the relation of the upper New Albany to the lower Cuyahoga of Kentucky. Read (Read and Campbell, 1939) placed the Devonian boundary near the top of the New Albany on the evidence of fossil plants whose stage of development he recognized as Devonian.

PRESENT CLASSIFICATION

The classification at present is as follows:

Mississippian
- Rockford limestone
- Jacobs Chapel shale
- New Albany shale
  - Upper New Albany
    - Henryville formation
    - Underwood formation
    - Sanderson formation
      - Falling Run member

Upper Devonian
- Blackiston formation
  - Upper Blackiston member
  - Lower Blackiston member

Middle Devonian
- Blocher formation

Hamilton
- Silver Creek, Swanville, or Beechwood limestone

ACKNOWLEDGMENTS

Two years were spent on the study of the New Albany shale in the type district. A grant from the Penrose Bequest of The Geological Society of America permitted pursuit of the work in Kentucky, Ohio, and Tennessee. Fossils were found at most horizons and at many places, and, to secure greater accuracy of identification, much of the material was submitted to various authorities for study. G. Arthur Cooper identified many of the invertebrates; Charles B. Read identified all the plants; William L. Bryant studied the fishes; Chalmer L. Cooper identified the crustaceans; and John W. Huddle identified some of the conodonts. Without all of this assistance and the aid of the Penrose Bequest the work never would have been completed. I am truly grateful for all this help.

INDIANA

DISTRIBUTION

The New Albany is exposed in a belt 3 miles wide at the Ohio River in Floyd and Clark County, 10 to 15 miles wide north to Jennings County, and does not appear north of Bartholomew County, except in small isolated outcrops in Johnson County, and at Monticello and Delphi, in northern Indiana.

TYPE AREA

The name "New Albany black shale" was applied to this terrane by Borden (1874, p. 158) from the wonderful display of this shale in the vicinity of New Albany, Indiana. It is exposed in almost continuous outcrop more than 5 miles along the

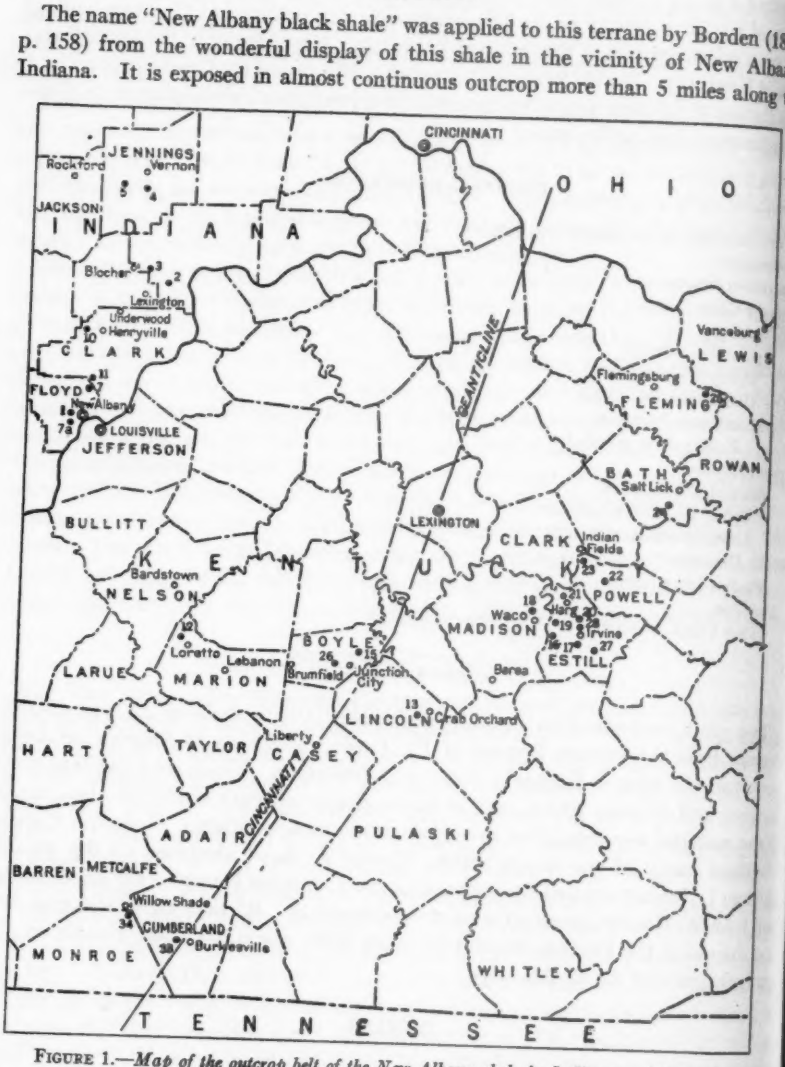

FIGURE 1.—*Map of the outcrop belt of the New Albany shale in Indiana and Kentucky*

banks of the Ohio River west of the Ohio Falls and along Silver Creek and its tributaries. Every lamina in the 100 feet of thickness can be studied while spread out like an open book in creek beds, and in their serial relations in the creek banks; many details are apparent that are not discernible elsewhere. These conditions permit a thorough exploration for fossils and account for a more complete faunal list

for the New Albany of Indiana than for other areas where the outcrops are limited vertical exposures.

The lower 35 feet of Section 1 occurs on the bank of the Ohio River at the mouth of Silver Creek; the bottom 1 foot of the Blocher is exposed at low-water stage at the dike, and the second to seventh feet are covered by water. The details of the Blocher are added from other sections. The section from the bottom of the Blackiston to the top of the New Albany is exposed from Armstrong's bend along Silver Creek to Blackiston Mill and west along Mount Tabor Creek to a point near Mount Tabor Church. The top of the lower Blackiston occurs at a sharp bend in Mount Tabor Creek, 0.25 mile west of highway 31W. The top of the Blackiston occurs 0.60 mile west of highway 31W., in the north angle of the Klerner and Mount Tabor roads. The total thickness of the New Albany in this area, as shown by wells, is 104 feet.

SECTION 1.—*Type section of the Blackiston formation. A connected section of the New Albany shale in the type region at New Albany, Indiana*

	Feet
Mississippian	
Rockford limestone	1.00 to 3.00
Jacobs Chapel shale, soft, greenish, glauconitic, fossiliferous	0.75
New Albany shale:	
Upper New Albany	
Henryville formation, fissile black shale; 24 species of conodonts 16 of which are common to the lower Sanderson, D1	1.00
(Underwood formation. This is the horizon of the Underwood shale, which is absent from the vicinity of New Albany. *See* sections No. 8 and 9)	
D. Sanderson formation	
D3. Falling Run member, a layer of phosphatic concretions; *Colpocaris, Spathiocaris, Lingula melie, Orbiculoidea herzeri, Dinichthys, Rhadinichtys*, abundant conodonts, and 15 species of plants	0.33
D2. Black shale, *Lingula* sp., fish dermal plates and teeth, conodonts, and 8 species of plants	1.00
D1. Black shale as in D2 with a layer of phosphatic nodules at the top; 46 species of conodonts, all common to the beds above	9.00
Upper Devonian	
Blackiston formation, 60 species of conodonts, 40 species confined to the Blackiston.	
C. Upper Blackiston member; hard, brittle, very thinly fissile black shale with much pyrite, interbedded layers of gray shale, and calcareous concretions.	
C4. Black shale with layers of sandstone ½ to 1 inch thick and flat calcareous concretions; silicified *Callixylon newberryi*	6.50
C3. Black shale, silicified *Callixylon*	10.00
C2. Black shale with large calcareous concretions	8.00
C1. Black shale with layers of gray shale and large calcareous concretions	7.00
Change of joints	
B. Lower Blackiston member; black shale with coarse laminae, brown shale filled with *Sporangites*, and gray shale; *Barroisella campbelli* in brown shale and gray shale only	
B6. Brown shale crowded with *Sporangites*, thin sheety laminae, and layers of gray shale; terminated by 2 layers of sandstone with *Sporangites* and *Barroisella*	5.00
B5. Black shale and gray shale layers	20.00
B4. Black shale with prominent widely spaced joints, which extend to the layer of pyrite below	15.00
B3. *Spathiocaris* zone; gray clay shale, which thickens to 15 feet and contains calcareous concretions at Hayden, 50 miles to the north	0.50
B2. Brownish-black to coffee-brown shale filled with *Sporangites*, thin sheety laminae, *Barroisella campbelli* abundant and well preserved	1.50
Layer of pyrite	
B1. Black shale with 4 layers of ripple-marked sandstone 1 to 4 inches thick. The two middle layers contain thin lime concretions and much pyrite. *Barroisella campbelli, Dinichthys magnificus*, many worn fish fragments, worm borings and trails, and matted masses of unidentifiable plants	4.50
Disconformity. Change of joints.	

Middle Devonian
Blocher formation, black shale with coarse laminae; 44 species of conodonts, 39 species confined to the Blocher
A3. Black shale with interbedded layers of ripple-marked sandstone..... 3.00
A2. Black shale..... 3.50
A1. Black shale with lenses and concretions of lime at top, lenses of sandstone at bottom; *Leiorhynchus, Styliolina* abundant; *Schizobolus* confined to the lower 1 foot..... 6.50
Layer of pyrite, 1 to 6 inches thick, often conglomeratic, is usually found at the base of the New Albany.
Hamilton limestones

NEW ALBANY CONODONTS

Conodonts described by Huddle (1934) furnish the most complete faunal evidence ever published for the New Albany. The writer is familiar with all the localities listed by Huddle (1934, p. 29–30) and to facilitate reference to those conodonts the following correlation of the zones he used (p. 11 and Fig. 2) is given. The Blocher, Blackiston, and upper New Albany as used in this paper (Fig. 3) coincide with the "lower," "middle," and "upper" conodont horizons of the New Albany, arbitrarily selected by Huddle in his study of the conodonts of the New Albany shale of Indiana. The "upper" horizon, 0 to 10 feet below the Rockford limestone, of Huddle, at localities 1 to 14, is equivalent to the upper New Albany of this paper, which includes the Sanderson, Falling Run, Underwood, and Henryville; the zone at locality 9 is confined to the Henryville; that at locality 5 to the upper bed, D2, of the Sanderson; and that at localities 4, 13, and 14 to the lower Sanderson bed, D1.

The "middle" horizon of Huddle, 15 to 50 feet below the Rockford, at localities 16 to 23, is equivalent to the Blackiston formation; the zones at localities 19 and 20 are in the lower Blackiston; those at localities 16, 17, 18, 21, and 23 are in the upper Blackiston; that at locality 22 is indefinite.

The "lower" horizon of Huddle, 0 to 15 feet above the base of the New Albany, at localities 26 to 33, is equivalent to the Blocher formation. Specimens in Huddle's list of species not specifically identified will not be included in comparative statements of conodont occurrence.

DESCRIPTION OF FORMATIONS

Basal conglomerate.—The New Albany rests on limestone of Hamilton age in Indiana. In Clark County it rests on different levels of the Silver Creek, Swanville, or Beechwood formation. A thin layer of pyrite, often conglomeratic, is usually found at the Hamilton contact. At some places it contains conodonts common to the Blocher.

At the Graves quarry in the northeast corner of lot 34 Clark Grant, 4 inches of black phosphatic conglomerate occurs at the base of the black shale, in shallow solution troughs in the upper surface of the Swanville limestone. This is an isolated outcrop of the Swanville and conglomerate and is surrounded on three sides by Beechwood limestone. The matrix of the conglomerate is a hard, jet-black, phosphatic material with fine texture, semimetallic luster when polished, and contains numerous disc-shaped pellets. The enclosed elongate rounded pebbles measure up to 3 inches in diameter and are composed of the same material as the matrix. *Pho-*

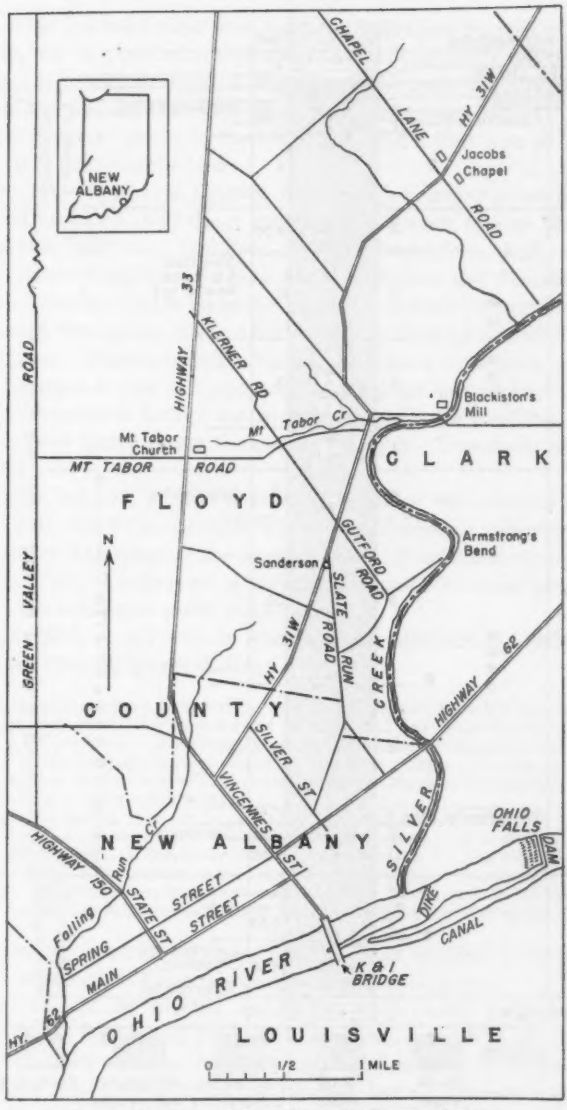

FIGURE 2.—*Map of New Albany, Indiana, and vicinity*

cops rana, *Stropheodonta*, *Orthoceras*, and a gastropod were collected from this layer. This layer differs from the conglomerate at the base of the New Albany elsewhere and may be a remnant of a bed of Tully age.

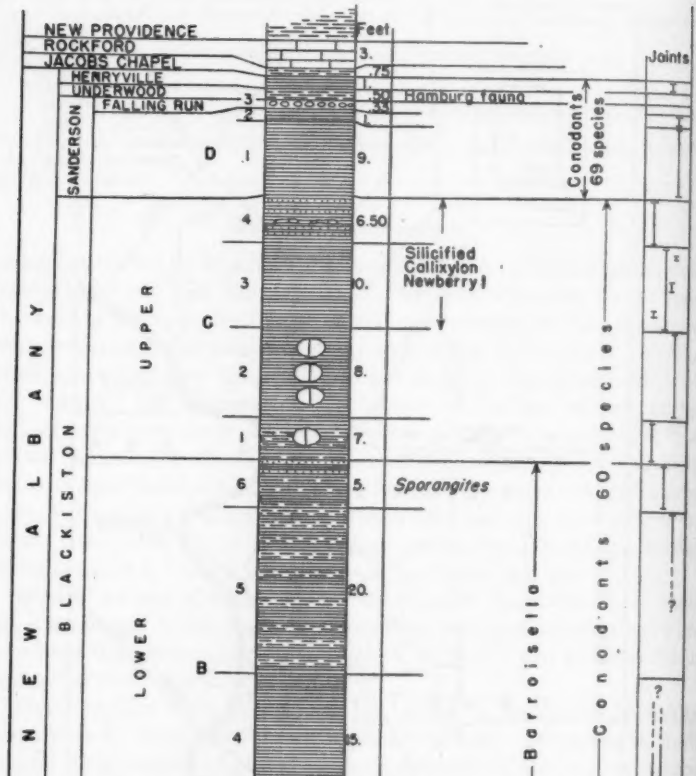

FIGURE 3.—*Illustrated section of the New Albany shale at New Albany, Indiana*

Blocher formation.—The Blocher shale is 8 to 10 feet thick at most places but varies from 2 to 15 feet. At some localities it includes at the top an additional bed 1 to 3 feet thick, composed of black shale and layers of sandstone, and at others post-Blocher erosion removed all but a foot of shale.

The Blocher is a black shale with comparatively thick laminae with subconchoidal fracture on one side and with a moderate amount of pyrite. There are sandstone lenses ½ to 1 inch thick in the basal portion at many localities. They extend laterally only a few feet and are often cross-laminated and ripple-marked. A small amount of calcareous matter occurs in the lower part, and a thin zone of calcareous lenses occur about 6 feet from the base.

Only the lower bed of the Blocher, A1, which is bounded above by the calcareous layer, contains fossils other than conodonts. *Chonetes lepidus* Hall, *Leiorhynchus quadricostatum* Hall, and *Styliolina fissurella intermittens* Hall are common to abundant at many localities. *Leiorhynchus*, *Styliolina*, and *Tentaculites gracilistriatus* Hall are abundant in the limestone layer. It is probable that *Tentaculites* occurs with *Styliolina* throughout the bed but cannot be distinguished under the conditions of preservation. *Lingula spatulata* Vanuxem is local in occurrence, and *Leiorhynchus limitare* Vanuxem is rare at Lexington. *Schizobolus concentricus* Vanuxem is confined to the lowermost foot of the Blocher and to a few localities. None of these species has been found above the calcareous layer. Conodonts occur throughout the Blocher.

The middle bed, A2, is present at most localities but contains only conodonts. The upper bed, A3, which contains layers of sandstone, is well represented at New Albany, on the Ohio River at the mouth of Silver Creek, and occurs 60 miles north of the Ohio River, 1½ miles east of Hayden, Indiana. It contains no fossils besides conodonts and occasional plant remains.

Whitfield (1875, p. 181–182) in discussing the affinities of fossils from the New Albany of the Ohio Falls area states:

> "Judging from the evidence furnished by the above mentioned species, I would not hesitate to say that the slates from which they were derived are in part at least equivalent to those known as the Genesee slates of New York. It is altogether probable that they represent both of the black slates of New York as well as the intervening shales of the Hamilton group; or, in other words, that they represent an equivalent in time to that of the entire Hamilton epoch as represented in New York, and perhaps even some of the overlying beds.
>
> Taking only the species that can be positively identified with those of New York, we have the *Discina (Trematis?) truncata*, *Lingula spatulata* and *Leiorhynchus quadricostata*, Hall, that are known only in the Genesee slates. *Chonetes lepida*, Hall, commences in the Marcellus shale and continues all through the group, occurring also in the Chemung group above. *Leiorhynchus limitaris* is known only from the Marcellus shale, and *Tentaculites fissurella* passes entirely through the Hamilton group".... "leaving the weight of evidence in favor of the upper member of the Hamilton epoch."

Discina truncata was from Lebanon, Kentucky and Whitfield was passing judgment on both the Blocher and Trousdale as recognized in this paper.

The lower bed of the Blocher corresponds very closely in faunal content and lithology with the Genesee of New York as recorded by Williams (1909). *Schizobolus* and *L. limitare* were not reported from the Genesee and *Orbiculoidea lodiensis* of the Genesee does not occur in the Blocher, but *O. lodiensis* is associated with *Schizobolus* in Kentucky. Williams placed the Genesee-Portage boundary at the top of the calcareous layer in New York, or above *L. quadricostatum* if it occurred higher; and the Portage with a *Manticoceras* fauna followed the Genesee conformably. In the Blocher calcareous lenses and *Leiorhynchus* end together and are followed by black shale and sandstone containing species of conodonts common to all the Blocher. The Blackiston formation with a *Barroisella-Manticoceras* fauna overlies the Blocher disconformably.

Cooper (1942) correlated that part of the New Albany identified by *Schizobolus*, *Styliolina*, and *Leiorhynchus* with the Geneseo shale or Tully limestone of New York and placed it in the Taghanic stage of the Middle Devonian.

Conodonts furnish additional evidence of the age of the Blocher. Huddle (1934) reported 44 species of conodonts from the "lower" New Albany, which is identical with the Blocher. In the lower 10 feet of the Blocher 44 species occur, 11 of these occur also in the summit bed of sandstone at Hayden. Only 3 of the Blocher species occur in the Blackiston and 5 in the Sanderson. Fifteen species are common to the Devonian of New York: 8 occur in the Rhinestreet, 9 in the Genundewa, and 3 in the Genesee. The Genundewa[1] species are confined to the Blocher.

Brachiopods and pteropods are plentiful in the creek bed between lots 196 and 213, and between 197 and 214, Clark Grant, east of Otisco; at the east side of Lexington in a quarry, and at the NE¼ sec. 3 T. 3. N., R. 8 E., Scott County; and at Hayden as located in section number 5.

Currents from the west in Blocher time are indicated by the arrangement of fossils at some localities. At some places at Lexington and Vernon *Styliolina* fills the limestone layer ½ to 2 inches thick. Portions of this layer have been collected in which the points of all specimens were directed toward the west. In the same layer at Hayden a thin band 6 inches wide, of closely crowded, overlapped, flattened specimens of *Leiorhynchus quadricostatum*, with the convex side up and all peaks pointing toward the west, extended along the creek for several feet. The brachiopods were probably attached to a plant that drifted from the west.

Blackiston formation.—The Blackiston formation is 75 feet thick and contains two members with different facies of black shale. Layers of gray shale are interbedded with the black shale of both members in the middle third of the formation. There are 40 or more layers of gray shale from ½ to 8 inches thick, separated by black shale 1 inch to 5 feet thick, and the total thickness of this zone is 27 feet. The gray shale in the thinner layers is more or less carbonaceous, but its argillaceous character is always evident by the lack of fissility and a tendency to crumble. The layers vary in color from light to dark gray or grayish black, and the laminae present an intricate pattern of light-gray *Spirophyton*-like markings on a dark-gray background, which is very conspicuous in creek beds when wet.

The great vertical extent and wide distribution of this middle zone of gray shale in the Blackiston is surprising; it is persistent throughout Indiana, Kentucky, Ohio, and central Tennessee east of the Central Basin. Previously, students of the New Albany have mentioned layers of gray shale at various levels and at scattered localities in Indiana and Kentucky, but they were in doubt as to the relation of the beds at different localities.

Eighteen species of conodonts and *Callixylon newberryi* range through the entire Blackiston, and on this evidence the strata are united as the Blackiston formation. A hiatus in the midst of the Blackiston, followed by a change in lithology and the restriction of *Barroisella campbelli* to the lower member, led to the division into members.

[1] For convenience the New York species are referred to as Genundewa and Rhinestreet conodonts, but there is no intention to imply correlation within the strict limits of these beds. The reported occurrence of the species from the Genundewa and Rhinestreet, only, does not connote a range restricted to those formations.

The lower 25 feet of the Blackiston is exposed at New Albany, on the bank of the Ohio River, between the mouth of Silver Creek and the bridge of the Kentucky and Indiana Terminal Railroad Company. The basal sandstone layers and about 30 feet of the overlying black-shale outcrop in vertical section at Armstrong's bend on Silver Creek, north of New Albany. About three fourths of a mile southwest of Armstrong's bend, at a south turn of Silver Creek, adjacent to the Gutford road, almost the entire Blackiston is exposed in vertical section for some distance along the creek. Due to the fine display of this formation in the vicinity of Blackiston Mill, an old land-mark and recreation center, Blackiston is a fitting name.

LOWER BLACKISTON MEMBER: Deposition of the lower Blackiston began in shallow water with the deposit of ripple-marked sandstone and black shale, followed by brown shale filled with *Sporangites*, and closed with brown shale followed locally by thin ripple-marked sandstone. The main mass of the lower Blackiston is a fissile black shale with coarse laminae and subconchoidal fracture.

On the Ohio River at the mouth of Silver Creek occur two beds of black shale, each with four layers of ripple-marked sandstone, and with separate joints and fossils. The sandstone in layers 1 to 4 inches thick is composed of very fine, well-rounded, clear quartz grains with mat surface, cemented by a small amount of lime. The crests of the ripple-marks are 3–6 inches apart and run in a general east-west direction. The two beds have no fossils in common. The lower bed includes conodonts common to the Blocher and is included with the Blocher formation; the upper bed contains *Barroisella campbelli*, which continues through the lower Blackiston.

The two middle layers of sandstone in the basal Blackiston bed contain much pyrite and many thin masses of lime, which usually contain a fish fragment or a plant specimen. *Barroisella campbelli* Cooper (formerly *B. subspatulata* (M. and W.)) first appears here, and *Lingula* sp. and *Cypridinella* n.sp. are rare. Flattened sections of tree stems and matted masses of plants, usually enclosed in lime or pyrite, are present but unidentifiable. Fish remains are common in the sandstone as worn fragments or whole specimens, and *Dinichthys magnificus* Bryant and Hussakof has been identified. Worm trails and borings are abundant.

The coffee-brown to brownish-black shale, bed B2, is medium hard and has rather tough, thin, sheety laminae. Between the mouth of Silver Creek and the K. and I. bridge, on the bank of the Ohio River, the upper 6 inches of this bed contains a thin layer of abundant *Barroisella campbelli*, many of which have the internal markings exquisitely preserved. Although spore cases may be detected on the surface of the laminae at most levels in the New Albany, and are abundant in the Falling Run, the top and bottom of the lower Blackiston are the only levels at which they occur in such numbers as to be a major constituent of the shale and determine its color.

DISCONFORMABLE BLOCHER-BLACKISTON CONTACT: The *Spathiocaris* zone of gray shale, bed B3, overlies the brown shale and is 18½ feet above the base of the New Albany at the Ohio River. At Lexington, 30 miles north, the gray shale overlies 10 feet of Blocher with the sandstone sparsely represented. Five miles northeast of Lexington, at Sharon Hill (section 2) only the basal 2 feet of the Blocher with *Schizobolus* separates the gray shale from the Swanville limestone. Thirty miles north of Lexington at Vernon (section 4), a single layer of sandstone separates the gray shale from the Blocher; and at Hayden (section 5), 5 miles west of Vernon, a zone of sand-

stone, which is included with the Blocher, separates the gray shale and Blocher black shale. The ripple-marked sandstone, worn fish fragments, and the variable thickness of the Blocher with the *Schizobolus* zone always present indicate erosion. This evidence and changes in lithology, jointing, and in fauna are evidence of a disconformity within the zone of sandstone, between the Blocher and Blackiston.

The lowest layer of gray shale, bed B3, in the Blackiston, 6 inches thick at the Ohio River, is a medium-hard, argillaceous shale. It contains abundant *Barroisella campbelli*, arranged at all angles to the bedding, and several clams. *Palaeoneilo* and *Preacardium* have been identified. North of the Ohio River this shale is softer and thickens uniformly until at Vernon and Hayden, 60 miles north, it is 15 feet thick and contains calcareous concretions, often septarian, 1 to 2 feet in diameter. This zone contains *Barroisella campbelli* and *Spathiocaris* sp. at Vernon and Hayden, and *Spathiocaris* is common at Hayden. For reference this bed will be called the *Spathiocaris* zone.

The major portion of the lower Blackiston is black shale. No fossils besides conodonts have been collected from the black shale, but *Barroisella campbelli* occurs in the interbedded layers of gray shale. The bed of brown shale, B6, at the summit of the lower Blackiston is the same in character as the brown shale at the base of the member.

CONODONTS OF THE LOWER BLACKISTON FORMATION: The following species of conodonts were collected from the lower Blackiston by the writer and identified by John W. Huddle. It contains species not before reported from the New Albany, and lots 1 and 2 are from horizons not represented in Huddle's list of New Albany conodonts (Huddle, 1934).

Lot 1. Conodonts from a layer of sandstone at the base of the Blackiston, 15 feet above the base of the New Albany, at the old Belknap quarry in Grant 89, Clark County, Indiana, 1 mile southeast of Sellersburg.

Polygnathus n.sp., *Polygnathus triangularis* Branson and Mehl, *Polygnathus linguiformis* Hinde, *Polygnathus sinelaminata* Branson and Mehl, *Ancyrognathus asymmetrica* (Ulrich and Bassler), *Ancyrognathus bifurcata* Ulrich and Bassler, *Ancyrodella lobata* Branson and Mehl, *Palmatolepis perlobata* Ulrich and Bassler, *Palmatolepis cymbula* Huddle. (John W. Huddle, letter April 22, 1943.)

Lot 2. Conodonts from the contact of beds B3 and B4, 19½ feet above the base of the New Albany, on the Ohio River at the mouth of Silver Creek, New Albany, Indiana.

Ancyrognathus inequalis (Holmes), *Bryantodus multidens* Ulrich and Bassler, *Bryantodus subcarinatus* Huddle, *Bryantodus* n.sp., *Hibbardella? divergens* Huddle, *Hindeodella aculeata* Huddle, *Hindeodella* aff. *H. catacta* Huddle, *Hindeodella* n.sp., *Lonchodina discreta* Ulrich and Bassler, *Lonchodina irregularis* Holmes, *Ozarkodina parva* (Huddle), *Palmatolepis subperlobata* Branson and Mehl, *Palmatolepis perlobata* Ulrich and Bassler, *Prioniodus alatoides* Holmes. This lot contained 170 specimens of *P. subperlobata* and 57 specimens of all other species. (John W. Huddle, letter April 22, 1943.)

Lot 3. Conodonts from a layer of sandstone at the top of the lower Blackiston, at the mouth of Falling Run Creek, on the Ohio river, New Albany, Indiana.

Ancyrognathus inequalis (Holmes), *Bryantodus coalescenoides* Huddle, *Bryantodus*

subcarinatus Huddle, *Diplododella* cf. *D. alternata* Branson and Mehl, *Hibbardella angulata* (Huddle), *Hindeodella aculeata* Huddle, *Hindeodelloides bicristatus* Huddle, *Lonchodina discreta* Ulrich and Bassler, *Ozarkodina parva* (Huddle), *Ozarkodina? subplanus* (Huddle), *Palmatodella delicatula* Ulrich and Bassler, *Palmatodella*? cf. *P. paridens* Huddle, *Palmatolepis glabra* Ulrich and Bassler, *Palmatolepis perlobata* Ulrich and Bassler, *Polygnathus varinodosa* Branson and Mehl, *Polygnathus nodocostata* Branson and Mehl, *Prioniodus alatoides* Holmes, and unidentified species of *Polygnathus*, *Ligonodina*, *Hindeodelloides*, *Hibbardella*, and *Metaprioniodus*. (John W. Huddle, Letter December, 1942.)

Specimens from all these horizons are still under study by Huddle, and many specimens remain unidentified, especially in the lot from the Belknap quarry.

The following sections are of the lower beds of the New Albany:

SECTION 2.—*Half a mile south of Sharon Hill Church, 5 miles northeast of Lexington, Indiana*

	FEET
Blackiston formation	
Black shale	
Gray shale (*Spathiocaris* zone)	3.00
Erosional disconformity	
Blocher formation, black shale with *Schizobolus*	2.00
Swanville limestone	

SECTION 3.—*Type section of the Blocher formation. One and one half miles southeast of Blocher, Indiana, 1 mile east of the Baltimore and Ohio Railroad, on highway 56*

	FEET
Blackiston formation	
Black shale	20.00
Spathiocaris zone, gray shale	3.33
Blocher formation	
Fissile black shale, *Leiorhynchus*, *Chonetes*, *Styliolina*	8.00
Pyritic conglomerate	
Swanville limestone	

SECTION 4.—*Two miles south of Vernon, Indiana, on highway 3*

	FEET
Blackiston formation	
Black shale	12.00
Spathiocaris zone, gray shale with calcareous lenses 3½ and 4 feet from the top; *Spathiocaris* sp. and *Barroisella campbelli*	12.00
Calcareous lenses and concretions	0.50
Gray shale	2.33
Coarse sandstone	0.66
Blocher formation, mostly covered	
Beechwood limestone	

SECTION 5.—*One and one-half miles east of Hayden, Indiana, extending north from highway 50 along a small stream to Six Mile Creek*

	FEET
Blackiston formation	
Black shale with layers of gray shale	
Spathiocaris zone, gray clay shale with numerous ellipsoidal calcareous concretions up to 2 feet in diameter; *Spathiocaris* common, and *Barroisella campbelli*	15.00
Blocher formation	
Black shale with thin layers of ripple-marked sandstone. (Huddle (1934) reported 11 species of conodonts from this bed, all common to the Blocher in the New Albany area)	3.00
Black shale with calcareous lenses and flat calcareous concretions in the upper part; *Leiorhynchus quadricostatum*, *Chonetes lepidus*, *Lingula spatulata*, *Styliolina fissurella intermittens*, *Tentaculites gracilistriatus*, and fish remains	9.00
Hamilton limestone	

The shale is covered at many intervals above the 9-foot level, and the measurements are approximate. *Spathiocaris* sp. occurs in the bed of the stream immediately south of the concrete bridge on highway 50.

UPPER BLACKISTON MEMBER: The upper Blackiston, 33 feet thick, is exposed for a mile along the Ohio River at the mouth of Falling Run Creek, and between Blackiston's Mill and Mount Tabor Church, 3 miles north of New Albany. It contains four beds of very thinly fissile jet-black shale with much pyrite, which is disseminated through the shale as pin-head-sized crystals. This member is more resistant to erosion than any other division of the New Albany and shows a variable appearance under different conditions of weathering. Where the surface is protected by overhanging Cliffs the laminae exfoliate, due to the formation of "copperas" which covers the face of the cliffs and characterizes this member in Indiana.

The beds of the upper Blackiston are distinguished by separate systems of joints and by the presence or absence of calcareous concretions and layers of gray shale. Layers of gray clay shale identical with that found in the lower Blackiston occur in the lowest bed; the middle beds contain black shale only; and the upper bed contains black shale, flat calcareous concretions, and thin layers of sandstone. Large calcareous concretions occupy the lower two beds. They are ellipsoidal, seldom spherical, 2 to 5 feet in diameter, and contain much carbonaceous matter, pyrite, and often dinichthyd remains. These concretions are found at this horizon northward in Indiana but do not extend south to the Ohio River.

The top bed of the Blackiston contains intercalated layers of sandstone ½ to 1 inch thick. The sandstone is fine-grained with impurities of carbon, lime, and pyrite and is often hardly distinguishable as a sandstone. It is rarely fissile to any great extent but is subject to jointing to a marked degree. The joints in two closely spaced sets divide the layers into almost rectangular sections of only a few square inches. The enclosing shale has other widely spaced joints. The small subrectangular sections of sandstone are very characteristic of this zone and are distinguishable over a large territory. A half-inch layer of sandstone with jointing characteristics identical with those just described occurs near the base of the Blackiston, 30 inches above the *Spathiocaris* zone, at many localities. Its stratigraphic associations prevent confusion with the layers in the top of the Blackiston.

The large flat concretions at the top of the Blackiston, sometimes several feet long and only a few inches thick, are found near the bottom of the bed, but they are different in texture and character from the large concretions in the lower bed of the upper Blackiston.

The two upper beds of the Blackiston are the source of the silicified *Callixylon newberryi* (Dawson) Elkins and Wieland common as weathered specimens in this area, and the silicified specimens have not been noted below this level in the present work. The specimens of *Callixylon newberryi* collected by Arnold (1931) 2½ miles east of Vienna, Indiana, came from the upper bed of the Blackiston, 15 feet below the top of the New Albany. At many places in Clark and Scott counties where weathered specimens of *Callixylon* are common the surface shale belongs to this zone. A large specimen of *C. newberryi*, probably 15 feet long, is in place in the shale of bed C3, on the bank of the Ohio River, at New Albany, Indiana. Jointed, carbonized

impressions of tree stems, some large, are common through the lower beds of the Blackiston. They have been identified as *C. newberryi*.

CONODONTS OF THE BLACKISTON FORMATION: Sixty species of conodonts have been identified from the Blackiston; 59 species occur in the lower Blackiston, and 19 in the upper Blackiston; 18 species are common to the two members. Three species are common to the Blocher, and 15 species ranged into the upper New Albany; 4 of the latter occur in the Henryville above the Underwood.

The Blackiston formation in northern Indiana occurs as follows:

SECTION 6.—*On the south bank of Deer Creek, southeast of Delphi, Carroll County, Indiana*

	Feet
Delphi shale	
Blackiston formation	
"Slaty" black shale with "copperas"	20.00
Rusty-black shale, weathers to chips	10.00
Soft, fissile black shale	1.25
Rusty-gray shale	0.80
Fissile black shale	5.00
Rusty dark-gray shale	0.75
Fissile black shale	5.75
Spathiocaris zone	
Gray clay shale with calcareous concretions	5.15
Gray clay shale	12.00
Limestone	0.67
Gray clay shale	5.50
Stony clay shale	0.67
Gray clay shale	4.00
Covered interval	
Hamilton limestone	

Kindle (1900, p. 563, 564, 573, 579) collected *Barroisella subspatulata* and *Spathiocaris emersoni* Clarke from the upper layer of the *Spathiocaris* zone at Delphi, and from a near-by outcrop, which he identified as the same horizon, he collected species of goniatites. Miller (1938) identified the goniatites as *Werneroceras wabashensis* (Kindle), *Manticoceras delphiensis* (Kindle), *M. Kindlei* Miller, and *M. undulocon-strictum* Miller.

The lithology and fauna of the Delphi shale identify it as Blackiston in age. On the evidence of their stratigraphic relations, lithology, and fauna the *Spathiocaris* zone at Delphi and in southern Indiana are regarded as contemporaneous (*see* Sec. 1-5), and on evidence to be presented below are correlated with the Olentangy shale of central Ohio.

Sanderson formation.—The Sanderson lies between the Blackiston and Underwood or Henryville. It is 10 feet thick and contains two beds, each with a layer of phosphatic nodules at the top. The Sanderson shale is less hard, less brittle, and less black than the upper Blackiston shale but is so similar that under varying conditions of weathering they cannot be distinguished by lithology. A large *Lingula* sp., *Rhadinichthys* sp., *Dinichthys*, large numbers of conodonts, small teeth, small fish scales, and large fish remains are found in the black shale. The small forms are very numerous along bedding seams. A large specimen of the posterior portion of the cranium of *Dinichthys* was found embedded in the top of the Sanderson, and ex-

tended through the Falling Run into the Henryville. Mandibles and other large fragments have been collected.

Fifty-four species of conodonts occur in the lower bed, 9 feet thick, and 7 species are common to the Blackiston. The discontinuous layer of nodules at the top of this bed has been observed for 50 miles north and 30 miles south of the Ohio River. The number of nodules varies from place to place, and the size varies from spherical forms an inch in diameter to flattened elongate forms 3 feet long. No fossils have been collected from the nodule layer, but plants were collected from the shale in the nodule layer at one locality. This horizon was referred to as the "plant bed" by Read and Campbell (1939). The following plants were identified: *Lyginorhacis dineuroides* Read and Campbell, *Clepsidropsis chaneyi* Read and Campbell, *Clepsidropsis bertrandi* Read and Campbell, *Pietschia polyupsilon* Read and Campbell, *Protolepidodendron microphyllum* Read and Campbell, *Protocalamites dorfii* Read and Campbell, *Asteroxylon setchelli* Read and Campbell, *Polyxylon elegans* Read and Campbell, and *Sporangites huronensis* Dawson.

The name Sanderson is proposed for this division of the New Albany from its ocation near Sanderson, a village 2 miles north of New Albany.

SECTION 7a.—*Type section of the Sanderson formation. In the northwest angle of the intersection of the Klerner and Mount Tabor roads, one mile northwest of Sanderson, 2 miles north of New Albany.* This section is the top portion of section 1.

	Feet
New Providence, gray shale	
?Gray shale, somewhat calcareous (may be Rockford)	1.00
Rockford limestone	2.00
Jacobs Chapel shale	0.50
New Albany shale	
Upper New Albany	
Henryville formation	1.00
Sanderson formation	
Falling Run member	0.50
Black fissile shale	1.00
Black fissile shale, layer of nodules at top	9.00
Blackiston formation, black shale with layers of sandstone	

SECTION 7b.—*Type section of the Falling Run member of the Sanderson formation. On Falling Run Creek, at the end of Market Street, New Albany, Indiana*

	Feet
New Providence shale	
Rockford limestone	1.00
Jacobs Chapel shale	0.50
New Albany	
Sanderson formation	
Falling Run member, layer of phosphatic nodules; plants, crustacens, conodonts, fish remains	0.25
Black shale, plants, *Dinichthys*.	

FALLING RUN MEMBER: The Falling Run member consists of phosphatic nodules and is the final phase of the Sanderson. It represents a near shore facies resulting from the retreat of the sea around the Cincinnati dome. This member has been traced from the Ohio River north for 45 miles to Uniontown, Jackson County, Indiana, and south and east through Kentucky to Irvine, Estill County. It is a

valuable datum plane, and since it has been given different time assignments by different workers and is related to the Maury shale of Tennessee, it is given a separate status as the Falling Run member of the Sanderson formation. As a member of the Sanderson its chronological position is beneath the Underwood formation, but in most of southern Indiana the Underwood is absent, and the Falling Run is overlain by the Henryville formation.

Apparently no black mud was deposited during the formation of the nodules, which were formed on top of the black shale, for they are imbedded partly in the upper laminae of the Sanderson and in the lower laminae of the Henryville. The nodules, in a single layer 2 to 3 inches thick, are very numerous and occupy all available space. Their size varies from half an inch in diameter to elongate flattened forms several inches long, but their thickness seldom exceeds 2 inches. They vary in texture, internal appearance, and faunal content, and there is evidence that they were not all formed at one time. In small patches in the layer of nodules the interstices are filled with a jet-black, granular substance composed of comminuted material that appears to be animal matter and contains numerous conodonts, small teeth, fish remains and some pyrite. Two clear quartz pebbles, about inch cubes, with rounded angles, were collected from the nodule layer. Plants occur in the matrix and nodules, invertebrates in the nodules only. Only a small per cent of the nodules contain fossils.

The Falling Run is exposed on Falling Run Creek at the west end of Market Street in New Albany, and wherever the top of the New Albany crops out in Floyd, Clark, and Scott counties.

The following species have been collected from the Falling Run in the vicinity of New Albany, Indiana:

Lingula cf. *L. cuyahoga* Hall, *Lingula melie* Hall, *Orbiculoidea herzeri* Hall, *Colpocaris bradleyi* Meek, *Colpocaris elytroides* Meek, *Colpocaris* sp., *Tropidocaris*? sp., *Spathiocaris woodfordi* Cooper, *Spathiocaris tenuicostatus* Cooper, *Spathiocaris striatula*? Cooper, *Angustidontus seriatus* Cooper, *Rhadinichthys*, *Dinichthys*, *Cladodus springeri*[2] St. John and Worthen, and other fish remains; *Kalymma lirata* Read, *Periastron perforatum* Scott and Jeffrey, *Periastron reticulatum* Unger, *Archeopitys eastmani*? Scott and Jeffrey, *Callixylon brownii* Read, *Clepsidropsis bertrandi* Read and Campbell, *Clepsidropsis titan*? Read, *Ctadoxylon* sp., *Siderella scotti* Read, *Lepidodendron boylensis* Read, *Reimania indianensis* Read and Campbell, *Protocalamites dorfii* Read and Campbell, *Asteroxylon setchelli* Read and Campbell, *Mensoneuron simplex* Read and Campbell, *Arnoldella minuta* Read, and *Sporangites huronensis* Dawson.

Underwood formation.—The Underwood shale lies between the Falling Run nodules and the Henryville shale. It has been observed at only three localities. At Underwood, Indiana, it is a soft, greenish, 6-inch, fossiliferous shale with a layer of phosphatic nodules at the top. It is exposed 2 miles east of Underwood, at intervals, in a narrow outcrop extending east for half a mile. South of this outcrop a few hundred yards it is absent. *Chonetes seymourensis* Huddle, *Camerotoechia mutata*?

[2] Reported by John W. Huddle (1934)

Hall, and fragments of other brachiopods occur in the shale and nodules. *Periastron reticulatum* Unger was collected from the shale.

SECTION 8.—*Type section of the Underwood shale. On the S. Ester farm, in the SE. ¼ sec. 21, T. 2 N., R. 8 E., 2 miles east of Underwood, Indiana*

	Feet
Rockford limestone	
Jacobs Chapel shale	
Upper New Albany	
Henryville black fissile shale	1.00
Underwood formation, soft, greenish, fossiliferous shale with a layer of phosphatic nodules at the top	0.50
Sanderson formation	
Falling Run member	0.25
Black shale	

Four miles southeast of the Underwood locality, in the NE. ¼ lot 244 Clark Grant, on the John Kern farm, nodules containing the Underwood fauna, but without the greenish shale, are bedded with Falling Run nodules bearing the *Lingula melie* assemblage. At this location weathered nodules and cherty debris cover the ground over several acres, and nodules containing the *L. melie* fauna predominate. Other nodules contain a rich Underwood fauna as follows: *Chonetes seymourensis* Huddle, *Rhipidomella oweni* Hall and Clarke, *Camarotoechia mutata*? (Hall), *Dielasmella compressa* Weller, *Tylothyris* cf. *T. clarksvillensis* (Winchell), *Camarophoria* cf. *C. hamburgensis* Weller, *Hamburgia*?, *Ambocoelia*, *Syringothyris* cf. *S. halli* Winchell, *Nucleospira*, *Schuchertella*, *Modiomorpha*, *Parallelodon*, *Platyceras* 2 sps., and other clams.

These species occur inside some nodules and adhering to the outside of others, and they are plastered to the outside, but never occur inside, of nodules containing the *L. melie* fauna. At this locality the nodules cover the ground profusely in a strip 100 yards wide at intervals for 300 yards. Nodules containing the Underwood species are found in a strip 50 feet wide running east-west through the main strip of nodules. At other localities the Underwood fossils have been observed adhering to nodules but without the gray shale.

The Underwood crops out at Rockford, Jackson County, and stratigraphic relations, lithic similarity, and identical species indicate the continuity of the beds at Underwood and Rockford.

SECTION 9.—*Two miles north of Rockford, Indiana, in the side ditch along the old route of highway 3*

	Feet
Henryville formation, black shale, *Lingula melie*, *Orbiculoidea herzeri*, conodonts	1.00
Underwood formation, gray shale with *Chonetes seymourensis*, *Camarotoechia mutata*?, *Rhipidomella*, *Tylothyris* cf. *T. clarksvillensis*, and other species exposed	2.00

Huddle (1933) reported *Chonetes yandellanus seymourensis*, *Camarotoechia eximia* Hall, *Rhipidomella vanuxemi newalbanyensis* and *Platyrachella* cf. *P. macbridei* (Calvin) from the gray shale at Rockford, and *Lingula otheri* and *Orbiculoidea lodiensis media* from the overlying black shale (Henryville), and assigned the beds to the Devonian. G. A. Cooper (1942, p. 1774) correlated the marine fauna of Huddle with the Hamburg and Bedford and agreed with Huddle on the Devonian age of the New Albany to the top of gray shale faunal zone.

The Bedford, Underwood, Hamburg, and Glen Park contain closely related faunas within similar faunal boundaries. In Kentucky the Falling Run nodules are associated with the Underwood west, and the Bedford east, of the Cincinnati arch, and the upper New Albany flora is common to all three beds.

Henryville formation.—The Henryville shale is the summit bed of the New Albany. It overlies the Falling Run, or the Underwood, where it is present, and is overlain by the Jacobs Chapel shale. It may be seen at many places along the course of Falling Run Creek in the vicinity of New Albany, and northward wherever the top of the New Albany crops out. A typical section is conveniently located on Falling Run Creek, at the west end of Market Street in New Albany.

The Henryville is a fissile black shale and cannot be distinguished from the Sanderson shale except by the presence of the Falling Run or Underwood between the two. It is never over 1 to 2 feet thick. *Lingula melie*, *Orbiculoidea herzeri*, and 22 species of conodonts occur in the Henryville, above the Underwood, at Rockford. Sixteen of the conodont species are common to the Sanderson shale and thus tie the Sanderson, Falling Run, Underwood, and Henryville in a single black-shale faunal unit with the Underwood fauna the critical factor.

SECTION 10.—*Type section of the Henryville formation. On Caney Fork Creek, in Clark Grant 252, 1½ miles southwest of Henryville, Indiana*

	FEET
Rockford limestone	
Jacobs Chapel shale, gray to greenish shale in three layers, the upper layer calcareous; fossiliferous	0.75
Upper New Albany	
Henryville formation, black fissile shale, conodonts	1.00
Sanderson formation	
Falling Run member	0.25
Black shale	

NEW ALBANY FAUNAL ZONES

A black mud environment tenanted by conodont-bearing animals and fish occupied the New Albany interior sea, and, at times, influxes of calcareous or argillaceous sediments, which brought species representative of outside regions, disrupted normal conditions and either replaced or modified the regular carbonaceous sediments. This sea with its peculiar black-mud environment was a realm unto itself, had its own rate of development of restrictive forms, was independent of the life stream in other sediments, and was a barrier to the mingling of other facies faunas from bordering provinces as effective as a land mass would be. Black-shale deposition lasted from late Middle Devonian well into Early Mississippian, but only three exclusively black-shale life zones are represented, and only conodonts show connected vertical relations through the entire section.

The three conodont zones, separated by two major breaks, conform to the Blocher, Blackiston, and upper New Albany boundaries, and a minor break separates the two members of the Blackiston. The upper New Albany comprises the Sanderson, Falling Run, Underwood, and Henryville. No plant or animal species besides conodonts is known to have ranged across the three New Albany zones.

The Blocher formation contains 44 species of conodonts, which occupy all the formation. Fifteen species are common to the Genundewa and Rhinestreet of New

York. The Genundewa species are confined to the Blocher, but the Rhinestreet species occur in higher beds. The Geneseo brachiopods are confined to the lower half of the formation, which is more or less calcareous.

The Blackiston formation is separated from the Blocher by a disconformity and contains a new faunal assemblage. Sixty species compose the Blackiston conodont assemblage; a majority are from the lower member, but 18 species are common to both members. *Ancyrodella*, *Ancyrognathus*, *Polylophodonta*, *Icriodus*, and *Palmatolepis*, given by Branson and Mehl (1938) as diagnostic Devonian genera, are characteristic of the Blackiston and do not range above its boundary except one species of *Palmatolepis*. Four species persisted from the Blocher into the Blackiston, and 13 species ranged from the Blackiston into the upper New Albany. Five Blackiston species occur in the pre-Welden of Oklahoma, and 10 species, all in the lower Blackiston, are common to the Grassy Creek of Missouri. *Barroisella campbelli* occurs with or below *Dinichthys magnificus* and *Callixylon newberryi* in southern Indiana; with *Manticoceras* in the Delphi shale in northern Indiana; and below *Tornoceras* in the Antrim shale in Michigan (G. A. Cooper, 1942), all of which are Devonian forms. In the New Albany, Indiana, area *B. campbelli* and its associates are interbedded with the conodont fauna, and a Devonian age is given to the entire Blackiston assemblage.

At most places north of the Ohio River the Underwood gray shale is absent, and the Sanderson and Henryville are indistinctly defined; other than the conspicuous nodules in the Falling Run there is little to differentiate the two formations. However, the Underwood shale with Hamburg species, between the Falling Run and Henryville, led to the segregation and naming of the divisions. These units are useful in tracing and correlating the beds, and their treatment as a sequence under the term upper New Albany best shows their relations to the New Albany black-shale life zones and to other formations.

Branson and Mehl (1938, p. 129) specify the *Ancyrodella* group of conodont genera as diagnostic of the Devonian, the *Siphonognathus* group as diagnostic of the Mississippian, and state that the break between these groups, as they appear in the Grassy Creek and Bushberg, constitutes one of the greatest in conodont history. This change in conodont life coincides with the break between the Blackiston and Sanderson. The break is little indicated by lithology, but is marked by an abrupt change in faunas and joints west of the geanticline. It can be recognized by a change in lithology east of the geanticline and is indicated by a conglomeratic sandstone at the base of the Sanderson horizon in central Tennessee.

Above this break occur a flora, *Dinichthys*, the Underwood fauna, and 20 species of Blackiston, Blocher, and Rhinestreet conodonts, all of which are recognized as Devonian elements by some geologists.

Associated with these elements are *Lingula melie*, *Orbiculoidea herzeri*, *Cladodus springeri*, and *Rhadinichthys* recognized as Mississippian, and a new conodont assemblage with Mississippian affinities predominant. The characteristic genera of the Blackiston are absent. *Synprioniodina*, *Solenognathus*, *Siphonognathus*, *Falcodus*, and *Spathodus* are represented by 17 species in the upper New Albany, 2 in the Blackiston, and 1 in the Blocher. A large number of individuals represent these

genera in the upper New Albany. *Siphonognathus newalbanyensis* Huddle is abundant at all levels in the upper New Albany and has been reported from the pre-Welden of Oklahoma and Bushberg of Missouri. *S. newalbanyensis* Huddle is synonymous with *S. quarduplicata* Branson and Mehl and *S. sexplicata* Branson and Mehl according to Branson and Mehl (1938, p. 131).

TABLE 2.—*Range of the New Albany flora and faunas*

	Bushberg conodonts	Hamburg fauna	*Lingula melie*	*Cladelus springeri*	Crustaceans	Upper New Albany flora	*Siphonognathus* group	*Callisylon newberryi*	*Ancyrodella* group	*Ternocras*	*Barrisiella*	*Manticoceras*	*Spathiocaris*	*Leiorhynchus*	*Styliolina*	*Tentaculites*	*Schizobolus*	Rhinestreet conodonts	Genundewa conodonts	*Lingulispora*	*Hypothyridina*	Bedford fauna	
Mississippian																							
Jacobs Chapel	x						x																
New Albany																							
Henryville	x		x				x																Sunbury
Underwood		x				x																x	Bedford
Falling Run	x		x		x	x	x																Cleveland
Sanderson	x		x	x		x	x											x					
Devonian																							
Blackiston								x	x	x	x	x	x					x					Olmsted
																							Huron
Blocher														x	x	x	x	x	x				
Trousdale																	x						Trousdale
Portwood																				x	x		Portwood

The Underwood and Henryville furnish the key to the upper New Albany relations. Sixty-nine species of conodonts occur in the upper New Albany; 24 species can be allocated to the Henryville, and 16 of these are common to the Sanderson. *Lingula melie* and *Orbiculoidea herzeri* occur in the Falling Run and Henryville. Three species of plants are common to the lower Sanderson and Falling Run and one of these occurs in the Underwood. The conodonts, brachiopods, and plants unite the upper New Albany members in a single life zone with the Underwood fauna in its midst.

C. L. Cooper (1936) correlated the pre-Welden of Oklahoma with the Bushberg-Hannibal on the evidence of 63 species of conodonts. Eighteen pre-Welden species occur in the upper New Albany; 5 in the Blackiston; 2 in the Blocher; and one of the latter occurs in the Rhinestreet. No Bushberg or Hannibal species occurs among the pre-Welden species in the Blackiston or Blocher, but 7 Bushberg and 1 Hannibal species occur in the upper New Albany. On the evidence of *Lingula melie*, *Orbiculoidea herzeri*, the *Siphonognathus* group of genera, and the pre-Welden and Bushberg species, which appear above the break in faunas, the lower Mississippian boundary is placed at the base of the Sanderson formation.

MIXED CONODONT ASSEMBLAGES

The upper New Albany and beds in other areas that appear to correlate with it have conodont assemblages with both Devonian and Mississippian affinities. The study of conodonts has not reached a stage that permits an age classification for a majority of the species.

Sixty-nine species of conodonts have been described from the upper New Albany, and 60 from the Blackiston. Twenty of the former occur in older beds: 11 species occur in the Blocher and Rhinestreet, and 13 in the Blackiston; 4 of the latter are common to the Blocher and Rhinestreet.

Branson and Mehl's (1940, p. 203) interpretation of the mixed Devonian and Mississippian assemblage in the "upper New Albany conodont zone" of Huddle (1934, p. 11) is partly expressed as follows:

> "Huddle seems to have included in the upper New Albany what appears to be a variable but always small thickness of highly weathered, comparatively soft, upper part of the black shale. We believe that this is the residuum of the weathered black shale developed in pre-Rockford time and reworked with the first advance of the Mississippian sea. This residuum seems to have had few New Albany conodonts so that the Bushberg fauna is nearly pure . . . .Most, if not all, of the actual stratigraphic mixture that appears in Huddle's upper New Albany is the result of the inclusion in the zone of some specimens from the shale along with those collected from the zone that appears to be the weathered black shale but is really the reworked residuum from the New Albany.
>
> Huddle's zonal collecting, his exact recording of types, and his good illustrations and descripinos make it possible to separate with fair certainty his list of New Albany species into New Albany (Devonian) and Bushberg (Mississippian)."

Neither Branson and Mehl nor Huddle had a clear understanding of the position and limits of Huddle's "upper" and "middle" conodont zones. Huddle (1934) gave the limits of the "upper conodont horizon" as extending down to 10 feet below the Rockford limestone, but, in the illustrated section in Figure 2, opposite page 11, he shows the upper conodont fauna with *Callixylon newberryi* and *Cladodus springeri* overlying a layer of nodules (Falling Run). This in turn overlies a gray shale (Underwood), the source of Huddle's (1933) invertebrate marine fauna, and he indicates as doubtful the presence of the upper conodont fauna below the Devonian invertebrates. This would limit the upper conodont fauna to the Henryville, which is nowhere over 2 feet thick, usually only 1, and the correct position of the "Devonian" invertebrates is between the Falling Run and Henryville.

Huddle's opinion appears to be that the New Albany is Devonian to the top of the Underwood, and he gave an estimate of 5 feet for the thickness of the overlying black shale; the estimate was wrong. When the upper 5 feet of the New Albany is used as the extent of the zone of species with Mississippian affinities, as was done by Huddle, Stockdale (1939), Branson and Mehl (1940, p. 203), and G. A. Cooper (1942, p. 1774), it includes the Falling Run and part of the Sanderson below the Underwood. The number of feet is not important, but the fact that at some localities in the vicinity of New Albany the Sanderson, Falling Run, Underwood, Henryville, Jacobs Chapel, Rockford, and New Providence occur within the limits of a yardstick, makes uncertain any blanket use of 5 feet for any zone at this horizon.

The Henryville, described by Branson and Mehl (1939, p. 11) as the "highly weathered, comparatively soft upper part of the fissile black shale," is soft only where it *is* weathered. It has the same hard brittle character as the underlying 40 feet of

shale. Huddle's limits of 0 to 10 feet below the Rockford for the upper conodont zone are near the limits of the upper New Albany of this paper, which was determined by all stratigraphic and faunal evidence. Only 5 species of conodonts common to the underlying Devonian beds appear in the Henryville, but 19 species from the Devonian beds range into the upper New Albany as a whole.

The occurrence of the Devonian species was checked against the assemblages at different levels in the upper New Albany. Thirty-three species occur in the middle zone of the Sanderson, which should represent a pure Sanderson assemblage; 7 species are common to the Blocher and Rhinestreet and 4 to the Blackiston. Twenty-one species occur in the basal Sanderson with one each from the Blackiston, Blocher, and Blackiston, and Rhinestreet. Sixty-eight species occur in the upper New Albany as a whole; 13 are common to the Blackiston, 5 to the Blocher, and 8 to the Rhinestreet.

Stratigraphic admixture does not appear to be supported by these facts, or, if present, continued through all the upper New Albany. Stratigraphic admixture does not explain the presence of six species common to the Blocher and eight common to the Rhinestreet. There was no advance of the sea that would give opportunity for admixture after the beginning of the Sanderson, in fact the sea was regressive during the latter part of the upper New Albany. It appears that the Devonian species were present in the Mississippian upper New Albany as a part of their range.

The failure of Branson and Mehl to correctly interpret the New Albany stratigraphy was due to incomplete and incorrect knowledge. The boundary between the two groups of conodont genera, which they designate as the Devonian-Mississippian boundary and locate between the Grassy Creek-Glen Park and Bushberg, in Missouri, occurs between the Blackiston and Sanderson, not at the base of the Henryville, in Indiana. Thus the Underwood, a correlate of the Hamburg and Glen Park, is included in the Mississippian.

FORMATIONS OVERLYING THE NEW ALBANY SHALE

General statement.—Early opinion included the New Albany black shale and the New Providence gray shale in the Devonian. The assignment of the Rockford limestone to the Mississippian by Meek and Worthen (1861) placed a ceiling over the New Albany, and subsequently the New Albany has been considered as a terrane distinct from the overlying formations. The present study demonstrates that the upper New Albany is more closely related to the Early Mississippian than to the Upper Devonian. Loose stratigraphy that groups strata by color and lithology alone is no longer permissible in the consideration of the black shales, and their re-examination on a faunal basis is imperative.

Jacobs Chapel shale.—Nine inches of soft, greenish to dark-green, glauconitic, sparsely fossiliferous shale lies between the top of the New Albany and the Rockford limestone. Newsom (1901) included it with the Kinderhook, and Huddle considered it a part of the Rockford (1934), but neither gave any reason for his assignment. The Jacobs Chapel shale may be seen at most localities in Floyd and Clark County where the Rockford is exposed. A typical section occurs near Jacobs Chapel church and school.

The Jacobs Chapel is fossiliferous at some localities, but the slumping of the Rockford makes collection difficult, and the poorly preserved condition of the specimens makes identification unsatisfactory. The following have been collected: *Menisco-phyllum,? Chonetes, Rhipidomella, "Spirifer", Platyceras*, minute gastropods, trilobites, ostracodes, and conodonts. Typical Bushberg conodonts occur in the zone

TABLE 3.—*Range and distribution of New Albany conodont species*

	Total species	Henryville	Upper New Albany	Sanderson	Blackiston	Blocher	New York Devonian	"Hardin," Tennessee	Chattanooga, Alabama	Woodford, Oklahoma	Ark. novaculite, Arkansas	pre-Welden, Oklahoma	Grassy Creek, Missouri	Bushberg, Missouri	Hannibal, Missouri
Henryville	24		24	16	4	2	1	1	2			8			
Underwood	0														
Upper New Albany	69	24		43	13	6	8	2	6	2	3	18		5	1
Sanderson	45	16	43												
Blackiston	60	4	13			3	4	6	12	5	8	4	10		
Blocher	44		6	5	3		15								

between the fissile black shale and the massive Rockford limestone according to Branson and Mehl (1940).

SECTION 11.—*Type section of the Jacobs Chapel shale 1 mile west of Jacobs Chapel Church, in lot 85 Clark Grant*

	Feet
Rockford limestone	3.00
Jacobs Chapel shale, fossiliferous	0.75
New Albany shale	
Henryville formation	1.00
Sanderson formation	
Falling Run member	0.33
Black shale	

Rockford limestone.—The Rockford limestone was named from Rockford, Indiana, the home of the Rockford goniatites. Borden (1874, p. 45) states: "This limestone at Rockford passes upward into greenish gray, hard, calcareous shale, filled with fossil cephalopod shells, in a fine state of preservation." The Rockford is now submerged due to the construction of a dam across White River at Rockford, and only an occasional goniatite may be found on the gravel bar below the dam.

The Rockford is present above the New Albany everywhere in southern Indiana but does not occur south of the Ohio River. It is a hard, mottled gray to greenish, fine-grained limestone that weathers brownish. At some localities in the Ohio Falls area 6 to 12 inches of hard, gray, calcareous shale overlies the Rockford limestone and may represent the goniatite layer at Rockford. The Rockford is usually in a single layer but may be composed of several layers. The under side of the bed is undulating corresponding to the low wide undulations in the top surface of the New Albany. A loose slab of Rockford limestone collected from the creek bed contains a well-preserved imprint of a profusely branched rill mark in relief. The upper surface of the Rockford is undulating also.

NEW ALBANY SHALE IN KENTUCKY WEST OF THE CINCINNATI ARCH

DESCRIPTION OF FORMATIONS

General statement.—The New Albany shale extends into Kentucky with only minor changes in lithology, but with a gradual thinning to the south and east toward the Cincinnati arch. This uniformity in lithology prevails to Lebanon, which approximates the position of the crest of the arch in New Albany time. East of Lebanon the lithology corresponds to the characters prevalent east of the arch.

The Henryville, Jacobs Chapel, and Rockford have not been observed south of the Ohio River. The New Albany has been removed from much of Jefferson County by recent erosion, except a few remnants of the basal portion with *Schizobolus*.

Trousdale formation.—The basal bed of the New Albany in Kentucky contains abundant *Schizobolus concentricus* Vanuxem through its entire thickness and is without the *Leiorhynchus* assemblage that occurs above *Schizobolus* in Indiana. This change in faunal content becomes evident just south of the Ohio River; the *Schizobolus* shale prevails in Kentucky, and in Tennessee, where it was described and named Trousdale shale by Pohl (1930). Since there is no apparent difference in this layer in this area, the bed in Kentucky is identified as the Trousdale shale.

The *Leiorhynchus* and *Schizobolus* zones are distinct but are contained in a single bed of black shale and in a single conodont zone in Indiana. There was no apparent break in sedimentation between the two zones. The bed in Kentucky contains more and thicker lenses of limestone, which is especially noticeable in Larue County, and the Trousdale-Blackiston contact is without the two beds of sandstone present in Indiana. *Schizobolus concentricus* Vanuxem is common to abundant, and *Leiorhynchus* and *Orbiculoidea lodiensis* Vanuxem are rare.

Blackiston formation.—A good section of the Blackiston occurs in the railroad cut at Gap in Knob, at the north side of Bullitt County, where 35 feet is exposed, which includes nearly the entire zone of gray-shale layers; and the Blackiston crops out in the vicnity of New Haven, Chicago, and Loretto. A good section of the entire New Albany, which contains the gray-shale zone and the sandstone layers in the upper Blakiston, is exposed across the road from the village store in Chicago, Marion County. *Barroisella campbelli* and brown shale with *Sporangites* were collected in Bullitt County, and silicified *Callixylon newberryi* was noticed at several localities in Marion County.

Sanderson formation.—The main body of black shale of the Sanderson presents no difference from the formation in Indiana except that phosphatic nodules become more numerous through the bed eastward, and the Falling Run member differs in color.

FALLING RUN MEMBER: The Falling Run, which consists of black phosphatic nodules with a scanty black matrix and is overlain by the Underwood, Henryville, Jacobs Chapel, Rockford, and New Providence in Indiana, is composed of gray nodules, which are imbedded in gray shale. It is overlain by the New Providence in Kentucky. The first outcrop of the gray shale and nodules observed south of the Ohio River is near the Jefferson-Bullitt County line. No outcrop shows a transition zone between the black- and gray-shale facies at this horizon. The bed of gray shale

and nodules has been regarded as basal New Providence by all previous workers, but the many fossils common to the Sanderson place the bed in the New Albany.

At most localities animal species may be collected from the nodules, but plant specimens occur at only a few localities. The greater number of plant specimens have been collected from the gray shale. The basal layer of nodules, only, is identified as the Falling Run; the accompanying gray shale is identified as the Underwood. The following species were collected 1 mile east of Boston, Nelson County, on the north side of highway 62; at Holy Cross, 5 miles north of Loretto, Marion County, on highway 49; and at Pine Lick, 1 mile northwest of Loretto:

Lingula melie Hall, *Lingula* cf. *L. cuyahoga* Hall, *Orbiculoidea herzeri* Hall and Clarke, *Colpocaris bradleyi* Meek, *Colpocaris elytroides* Meek, *Rhadinichthys*, *Angustidontus seriatus*[3] Cooper; *Kalymma lirata* Read, *Archeopitys eastmani* Scott and Jeffrey, *Callixylon brownii* Read, *Clepsidropsis bertrandi* Read and Campbell, *Clepsidropsis titan* Read, *Pietschia polyupsilon* Read and Campbell, *Steloxylon sanctae-crucis* Read and Campbell, *Lepidostrobus kentuckiensis* Scott and Jeffrey, and *Lepidodendron*. All except the last three are found in the Falling Run at New Albany, Indiana.

Underwood shale.—The nodules of the Falling Run contain black-mud types of life that have not been found as residents of a gray-shale environment. The gray shale associated with the Falling Run has the lithology of the Underwood, and where the outcrop furnishes fresh material it can be distinguished from the New Providence by difference in color, a red parting, or at some places by the presence of an indurated upper layer. At Pine Lick a second layer of nodules occurs at the top of the gray shale. *Chonetes* and fragments of other brachiopods adhere to some of the nodules, and the brachiopods occur in the same manner at the section 1 mile east of Boston. The section at Pine Lick is reminiscent of the section at Underwood, Indiana (section 8). This gray shale, which overlies the Falling Run west of the Cincinnati arch, is identified as the Underwood shale. The relation of the Underwood and Sanderson will be discussed in connection with the Bedford shale in paragraphs following.

SECTION 12.—*At Pine Lick, 1 mile northwest of Loretto, Marion County, Kentucky*

	Feet
New Providence	
Light olive-green shale	
Dark-gray shale	8.00
New Albany shale	
Underwood formation	
Layer of nodules, *Chonetes*, etc.	
Gray clay shale, plants	0.50
Sanderson formation	
Falling Run member, layer of nodules; plants, brachiopods, crustaceans	0.33
Black shale	

NEW ALBANY SHALE IN KENTUCKY EAST OF THE CINCINNATI ARCH

GENERAL STATEMENT

The New Albany outcrop belt extends through Indiana and Ohio from north to south and crosses central Kentucky in the shape of a lower case *y*, straddling the

[3] Reported by C. L. Cooper (1936).

Cincinnati arch from Louisville and Vanceburg to Casey County, then extending atop the arch southwestward to Tennessee. All the divisions of the New Albany except the Underwood and Henryville were traced from Indiana into eastern Kentucky through sections so close and staggered that the chance of error was reduced to a minimum. The difference in the characters in the two areas is largely a matter of degree, and the lateral change is very gradual, but no faunal or stratigraphic change of importance occurs. The basal Trousdale can be identified by its position and fossils, and the summit Falling Run by its position, lithology, and fossils. The central zone of gray shale in the Blackiston is a colored plane of reference easily traced and is separated from both the Trousdale and Falling Run by beds of black shale. These characters furnish three color zones and two fossil zones, most of which can be recognized at most localities. East of the geanticline lithic features peculiar to the upper Blackiston and Sanderson supply additional diagnostic characters. The location of the vertical limits of the joint systems, when they are sufficiently exposed, aided in determining the boundaries of the different divisions.

The black shale of Kentucky has been treated as a part of the New Albany, Chattanooga, or Ohio shale by different workers. Although it is continuous in great part with all three, the shale above the Trousdale east of the Cincinnati arch more nearly conforms to the characters of the Ohio shale. The formations of Ohio represented within the limits of the New Albany are the Olentangy, Huron, Olmsted, Cleveland, Bedford, Berea, and Sunbury. The lower Blackiston, upper Blackiston, and Sanderson are equivalent to the Huron, Olmsted, and Cleveland respectively. The Olentangy is the basal member of the Huron.

SECTION 13.—*On Cedar Creek, on Hall Gap road, 2½ miles west of Crab Orchard, Lincoln County, Kentucky*

	FEET
New Providence shale	
New Albany shale	
Falling Run member of Sanderson formation, nodules	0.20
Bedford gray shale	0.50
Sanderson formation, "slaty" black shale with abundant phosphatic nodules throughout	10.00
Blackiston formation	
Upper Blackiston member (Olmsted)	
Black shale with calcareous layers and cone-in-cone, and two pyritic layers at the top. Neighboring sections show layers varying in hardness and alternate layers weathering out, leaving a series of shelves	10.00
Black shale alternating with gray shale	4.00
Lower Blackiston member (Huron)	
Impure black shale alternating with impure gray shale	7.00
Black shale	7.00
Olentangy shale, two layers of gray shale separated by black shale	0.50
Trousdale shale	8.50
Portwood formation, Duffin facies	

The Crab Orchard section, which is located near the union of the stems of the *y*, is an excellent medium for comparison of the black shale of east-central Kentucky and Ohio with that in west-central Kentucky and Indiana, and that of both areas with the Chattanooga shale of south-central Kentucky and Tennessee. The Crab Orchard is a brief section for eastern Kentucky and between the Trousdale and Falling Run represents an abbreviated section of the Ohio shale; with the omission

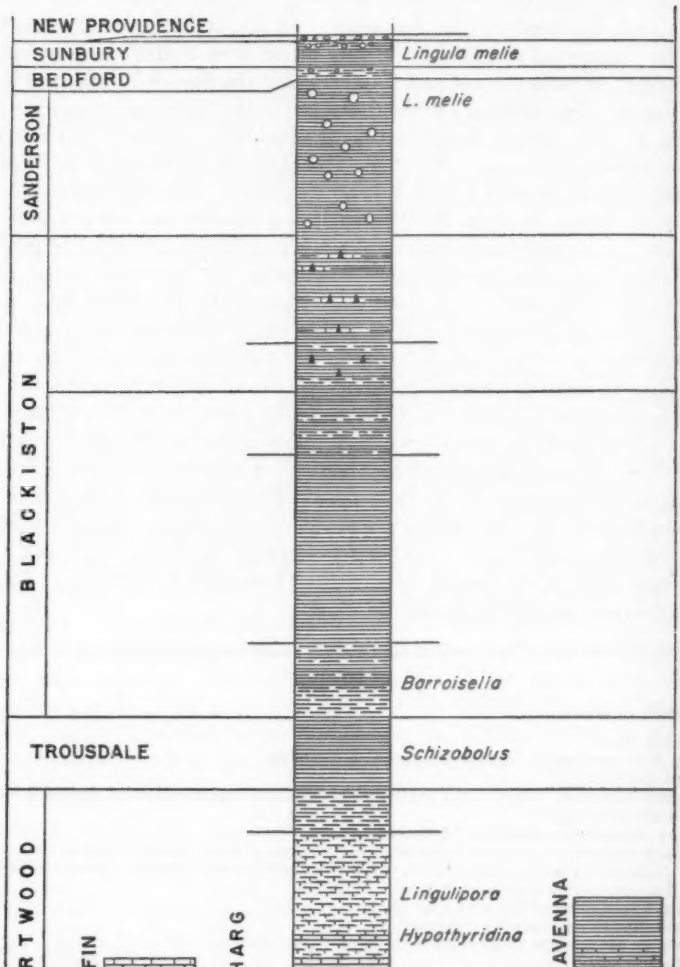

FIGURE 4.—*Illustrated generalized section of the New Albany shale in Estill County, Kentucky*

of the Duffin layer and minor changes in the lithology of the upper Blackiston, it would replace the type section at New Albany, Indiana.

THICKNESS OF THE NEW ALBANY

The New Albany shale thins from 104 feet at the Ohio River at Louisville to 50 to 75 feet in Marion County. The thickness of the Ohio shale was given by Morse and Foerste (1912) as 301.5 at Vanceburg; 189.5 feet at Fox Springs, Fleming County; and 93 feet at Olympian Springs, Bath County. Equivalent sections are 90 feet thick at Irvine; 46 feet at Crab Orchard; 32 feet at Liberty; and 25 feet at Burkesville. The last two localities are on the crest of the Cincinnati arch. The marked thickening north of Olympian Springs is largely confined to the Blackiston.

Data compiled from well records show the thickness under cover increases both east and west of the geanticline. The thickness of the New Albany by counties from west to east is: Grayson 137 feet, Hart 80–106 feet, Taylor 50 feet, Casey 30 feet (exposed), Pulaski 45–80 feet, and Whitley 140 feet.

The individual thicknesses of the Sanderson, Blackiston, and Blocher in Indiana are 10–78–13 feet respectively; in Kentucky the thicknesses of the Sanderson, Blackiston, and Trousdale are 21–64–10 feet at Irvine, 10–28–8½ feet at Crab Orchard; ?–?–10 feet in Allen County; in Tennessee, 12–15–6 plus feet at Bransford, and 9–19–0 feet at Bakers.

SECTION 14.—*Generalized section for Estill County, Kentucky and a complete representative section for east-central Kentucky*

	Feet
New Providence shale	
New Albany shale (equivalent)	
Sunbury shale	
Thin layer of phosphatic nodules	
Fissile black shale, phosphatic nodules scattered through the bed and arranged in a layer near the top. *Lingula melie* and *Orbiculoidea herzeri* abundant at the bottom	3.00
Bedford, soft gray shale with phosphatic nodules; thin layers of fissile black shale locally; fossiliferous	1.50
Sanderson formation (Cleveland)	
Fissile black shale, abundant phosphatic nodules	21.00
Blackiston formation	
Upper Blackiston member (Olmsted)	
Alternate layers of hard and less hard black shale with thin layers of lime with cone-in-cone	14.00
Black shale and gray shale interbedded	7.00
Lower Blackiston member (Huron)	
Black shale and gray shale interbedded	8.00
Black shale, thick-bedded, uniformly hard	25.00
Olentangy shale member, soft gray shale with thin layers of black shale	10.00
Trousdale formation, fissile black shale, *Schizobolus* abundant	10.00
Portwood formation, 3 coeval facies:	
Duffin limestone facies	0 to 3.00
Harg shale facies:	
Upper division, medium hard gray clay shale above, hard clay rock below	0 to 5.00
Middle division, carbonaceous-calcareous shale, hard, poorly fissile, dull black, weathers gray; lenses of limestone, sometimes dolomitic; *Linguli pora williamsana*, *Leiorhynchus* cf. *L. mesacostale*, *Hypothyridina venustula*, and *Emanuella* sp.	7 to 22.00
Lower division, dark-gray clay shale which weathers to chips	0 to 10.00
Ravenna shale facies, fissile black shale with lenses of limestone; *Linguli pora williamsana*	0 to 10.00

DESCRIPTION OF FORMATIONS

Portwood formation.—The Portwood formation, *Hypothyridina* zone is the basal stratum of the New Albany in eastern Kentucky and includes all beds between the Middle Devonian limestone and the Trousdale shale. It consists of the Duffin dolomite, Harg calcareous shale, and Ravenna carbonaceous shale as members, which are regarded as coeval facies within the *Hypothyridina* zone. The names Portwood, Harg, and Ravenna are proposed for these new divisions, which are here segregated for the first time.

DUFFIN DOLOMITE FACIES: A layer of dolomite with a brecciated appearance, lying at the base of the black shale in Lincoln County, was first described by Linney (1882). It was named "Duffin layer" from its typical development at the Duffin cut on the railroad north of Junction City and was mapped over a large area by Foerste (1906). Savage (1930) identified any limestone layer lying at the base of the New Albany throughout Kentucky as Duffin and, on the evidence of fossils collected at Irvine and Clay City, classified it as Tully in age.

The Duffin layer is a mottled, gray to brownish dolomite, which often presents a brecciated appearance. The color scheme consists of a gray base with lighter-colored spots, but there is no difference in composition of the "pebbles" and base, and no line of fracture between the two. This mottled appearance varies as to the size of the particles and sometimes presents a pepper and salt effect. Neither the brecciated appearance nor the dolomitic content is constant or confined to the Duffin, but both appear in older rocks.

The Duffin is typically represented in Boyle, Lincoln, and Casey counties, where it ranges from 3 to 8 feet thick, and eastward to Berea, and thins to 1 foot at Crab Orchard. It is absent northeast of Berea in Madison County and from most of Estill County. It is present on the western border of the New Albany belt of outcrop in Clark, Powell, Montgomery, and Bath counties to Olympia, where it wedges out. It is absent west of the Cincinnati arch, and its reported or inferred presence south of Casey County is not based on good evidence. The Duffin contains fossil fragments but is remarkably barren of identifiable specimens.

HARG SHALE FACIES: In the area between Berea and Olympia the basal layers of the New Albany are distinct in lithology and fauna from the superjacent Trousdale shale, and this tripartite facies is separated as the Harg facies of the Portwood formation. The lower and middle divisions are thickest and are typically represented at Witt schoolhouse, (section 20); and the upper division is best exposed at Rice Station (section 16). The three divisions are found together at Harg (section 21), and the name Harg is proposed for this facies of the Portwood.

The lower division of the Harg shale is greenish, gray, or bluish-black argillaceous shale, which weathers to chips, or at some places to a lumpy mass. It is 2½ feet thick and associated with layers of limestone at Harg, but is typically represented with a thickness of 10 feet, at Witt schoolhouse. At Waco, 6½ miles to the southwest, it is a hard clay rock weathering brownish. It is generally argillaceous throughout, but at Trapp on highway 89, it has several layers separated by thin layers of fissile black shale.

The middle division of the Harg is a carbonaceous-calcareous shale. It is hard, dull black weathering gray, poorly fissile, and commonly in thick layers with thin layers of fissile black shale. It is 9½ feet thick at Harg, but reaches a thickness of 23 feet at Witt schoolhouse and is 13 feet thick at Rice Station. It usually contains layers of limestone, which occur more often in the lower half, and is more constant in lithology than the other divisions of the Harg. *Lingulipora williamsana* Girty is abundant and found at most localities; myriads of tiny specimens cover the surface of the laminae at some localities. *Leiorhynchus* cf. *L. mesacostale* (Hall), *Hypothyridina venustula* (Hall), and *Emanuella* sp. are rare.

The upper division of the Harg is a stony, light-gray argillaceous shale, its layers varying in hardness, which often grades into a hard argillaceous rock. It is 3 feet thick at Harg, and at Rice Station, where it is 5½ feet thick, the lower half is a hard clay rock, and the upper half is a stony crumbly shale with the layers alternating in hardness At Portwood it has three layers, and the upper layer is calcareous and arenaceous. At Waco, less than a mile west of Portwood, it is a hard gray rock weathering buff and is 1½ feet thick.

The three divisions of the Harg seldom have the same relative representation at any two localities, and the lower division is more often absent. Layers of brown or black limestone occur at different levels in the two lower divisions and at some localities partially or entirely replace the shale. This is evident in the section at Harg. Different levels of the Harg rest on the Hamilton limestone, and often a layer of limestone belonging to the Harg is the basal layer of the New Albany, as illustrated at Harg and Rice Station. On Calloway Creek, between Witt schoolhouse and Harg, at a locality west of Clay City, and at Portwood, the middle division of calcareous shale rests on the Hamilton. At Waco both the lower and upper divisions consist of hard clay rock, the lower with some sand. Less than a mile east of Waco, at Portwood, the lower division is absent, and the upper division contains three layers of varying hardness with the top layer sandy.

The outcrop belt of the base of the New Albany covers Boyle, Casey, and Lincoln counties in the type area of the Duffin, but narrows to a single row of exposures, and the Duffin ends in the vicinity of Berea. From Berea northward the belt widens for 15 miles until it is 10 miles wide from Waco to Irvine. From there it again narrows abruptly and extends northeastward in a narrow, irregular belt past Indian Fields to Olympia.

From Berea to Waco and Rice Station, the Duffin is absent, except at one isolated outcrop at Brassfield, and is replaced by the Harg shale. From Waco and Irvine northward the Duffin occurs only on the western border of the outcrop belt, and the Harg predominates eastward. The lower and upper divisions of the Harg are limited to the Rice, Waco, Harg district, but the middle division extends from Berea to Indian Fields. The Duffin was probably present west of Waco, joining the northern region with the Duffin of the type area, but has been removed by recent erosion; and probably at many places in the Harg area calcareous layers have been identified as Duffin because they were basal to the New Albany when in fact they were parts of the Harg shale. Also, some of the fossils credited to the Duffin no doubt were collected from the Harg shale. The pseudo-brecciated character has been used as a

diagnostic character of the Duffin, but Foerste (1906, p. 194) describes a basal New Albany layer located 3½ miles west of Clay City as an "argillaceous rock, brecciated at the base as in the case of the Duffin, 9 feet thick, with brachiopods." Its lithology and thickness indicate the middle calcareous division of the Harg shale.

REVENNA SHALE FACIES: The Ravenna shale facies of the Portwood formation is a fissile black shale with lenses of black or brownish limestone; it is indistinguishable from the overlying Trousdale shale. It occurs only on the eastern border of New Albany outcrop and is exposed 1 mile west of Ravenna, at the southwest corner of Irvine, and in the vicinity of Indian Fields (Sec. 23) and Jeffersonville. At these localities *Lingulipora williamsana* is abundant and accompanies *Hypothyridina* and other brachiopods. The presence of the Ravenna shale under cover east of the Duffin-Harg belt is assumed.

COEVALITY OF THE PORTWOOD MEMBERS: The Harg shale replaces the Duffin limestone in the area where the former appears and is transitional between the Duffin and Ravenna shale. Fissile black shale interfingers with the Harg shale and, to some extent, with the Duffin limestone, and layers of limestone occur in the Harg and Ravenna. *Hypothyridina* and *Lingulipora* have been reported from all three facies and, together with their stratigraphic relations and lithology, determine their coevality. The Tully affinities indicated by *Hypothyridina* apply to all.

FOSSILS OF THE PORTWOOD FORMATION: Savage (1930, p. 17) reported *Hypothyris cuboides* (Sowerby)? and other species from the Duffin at Clay City and Irvine. The writer found no Duffin in the vicinity of Irvine and identified the lowest bed at that locality as Ravenna shale (Sec. 17). A section by Butts (1922, p. 7) at the same location is in accord with the characters given in section 17.

Foerste (1906) reported fossiliferous beds at the Portwood horizon on the road to Hammack, 3½ miles southeast of Lancaster; between Hudson's Mill and Snow Creek Church, 3½ miles west of Clay City; and at Rice Station. The writer collected *Hypothyridina venustula*, *Linguilpora williamsana*, *Leiorhynchus* cf. *L. mesacostale*, and *Emanuella* from the Harg shale at Harg, Waco, and Portwood.

Girty (1898) reported *Lingula williamsana* Girty and *Leiorhynchus quadricostatum* from Indian Fields; and *L. williamsana*, *Orbiculoidea* sp., *Leiorhynchus quadricostatum*, *Meristella* cf. *M. haskinsi*, and *Plethospira socialis* from Jeffersonville, Montgomery County, Kentucky. G. A. Cooper (1942, p. 1761) found *Hypothyridina venustula* (Hall) in Girty's collection from Indian Fields. Girty gives the distribution of *Lingula williamsana* as

> "in the Devonian black shale at Berea, Ky., near Vanceburg, Ky., near Jeffersonville, Montgomery County, Ky., Whites Creek Springs, Davidson County, Tenn., and also in the *Styliola* layer of the Genesee shale at Bristol, Ontario County, N. Y., where it is associated with *Lingula spatulata*."

The specimens from Indian Fields and Jeffersonville are very likely from the Ravenna shale, but the Trousdale and Blackiston are present at both localities. *Lingulipora* at Vanceburg indicates its presence in the Blackiston. The writer collected *Lingulipora* from the Blackiston at Clay City, Kentucky, and from the lower Blackiston at New Albany, Indiana, but has not identified it in the Blocher or Trousdale.

SECTION 15.—*Type section of Duffin layer along railroad in Duffin cut, 1 mile north of Junction City, Boyle County, Kentucky*

	FEET
Trousdale formation	
Fissile black shale and thin layers of limestone, *Schizobolus concentricus* abundant	12.00
Portwood formation	
Duffin dolomite facies	6.00
Hamilton limestone	
Ordovician	

SECTION 16.—*At the tunnel on an abandoned railroad, 1 mile southwest of Rice Station, 5 miles west of Irvine, Estill County, Kentucky*

	FEET
New Albany shale	
Blackiston formation	
Fissile black shale, the top poorly exposed	25.00
Olentangy shale member, interbedded black shale and gray shale	8.25
Trousdale formation	
Fissile black shale, *Schizobolus*	8.00
Fissile black shale with worm borings, interbedded with stony gray shale	3.00
Fissile black shale with *Schizobolus*	1.25
Portwood formation:	
Harg shale facies:	
Upper division, stony, crumbly gray shale with alternate hard and softer layers	3.00
Hard gray clay rock	2.60
Middle division, poorly fissile, dull-black, calcareous shale with lenses of limestone; *Lingulipora*	13.00
Brownish-drab rock	2.50
Hamilton limestone	

SECTION 17.—*Type section of the Ravenna facies one mile west of Ravenna, along the railroad at the southwest corner of Irvine, Estill County, Kentucky*

	FEET
Lower Blackiston member	
Fissile black shale	
Olentangy shale member, interbedded layers of fissile black shale and gray shale	10.00
Trousdale formation, fissile black shale, *Schizobolus*	5.00
Portwood formation	
Ravenna shale facies, fissile, black shale, more or less calcareous, with layers of limy or arenaceous shale and layers of limestone, which are more frequent at the bottom; *Lingulipora*	5.00
? Soft brown carbonaceous shale grading upward into gray argillaceous shale, closing with an iron-stained layer an inch thick; large *Lingula* sp. This bed may represent the lower division of the Harg shale	2.00
Beechwood limestone	
Cherty limestone	6.00
Shaly limestone, great abundance of *Ambocoelia umbonata*	0.50
Shaly limestone	0.66
Limestone in two layers	3.00

The Olentangy shale is also exposed a few hundred yards west of this section, along the Railroad.

SECTION 18.—*On highway 52, just north of Waco, Estill County, Kentucky*

	FEET
Trousdale formation, black shale with much calcareous matter and many worm borings	5.00+
Portwood formation:	
Harg shale facies:	
Upper division; fine-textured gray clay rock which weathers buff	1.50
Middle division; hard, black calcareous shale with worm borings, alternating irregularly with lenses of gray limestone; *Lingulipora*, *Leirohynchus*	6.00
Lower division; thick-bedded, sandy clay rock	2.50
Earthy, "wave-marked" clay rock	0.33
Brown fine-grained sandy limestone	1.66

SECTION 19.—*On highway 52, at the entrance to the Andrew McLaughlin farm, at Portwood, ¼ of a mile east of Waco, Estill County, Kentucky*

	Feet
Trousdale formation, fissile black shale with many worm borings, *Schizobolus*	5.00
Portwood formation:	
Harg shale facies:	
Upper division; decayed arenaceous, calcareous, argillaceous rock	1.75
Stony, crumbly gray clay rock	1.00
Hard gray clay rock	2.00
Middle division; hard calcareous shale, poorly fissile, (more fissil toward the top), and three layers of limestone 6 to 8 inches thick. *Hypothyridina, Leiorhynchus, Lingulipora*	10.00
Silurian shale	

SECTION 20.—*At Witt Schoolhouse, south of Calloway Creek, on highway 89, 1.4 miles northwest of Irvine, Kentucky*

	Feet
Portwood formation	
Harg shale facies	
Middle division; carbonaceous-calcareous shale, hard, blocky, poorly fissile, dull black, weathers gray, in layers 6 inches to 2 feet thick, with thin partings of fissile black shale	18.00
Limestone, brown to black	0.85
Calcareous shale as above	4.50
Lower division; hard, dark-gray clay shale, weathers to chips	10.00
Hamilton limestone	

SECTION 21.—*Type section of the Harg shale facies. In cut on the Louisville and Nashville Railroad, ½ mile north of Harg, 6 miles northwest of Irvine, Estill County, Kentucky*

	Feet
New Albany shale	
About 100 feet of shale is exposed in the vertical walls of the railroad cut, but only the lower part of the Blackiston is accessible for critical study.	
Blackiston formation	
Olentangy shale member, black and gray shale layers interbedded	10.00
Trousdale formation, black shale, *Schizobolus concentricus, Orbiculoidea lodiensis*	6.00
Portwood formation:	
Harg shale facies:	
Upper division; stony gray shale, contains impure darker layers of more indurated shale	3.00
Middle division; thick-bedded, subfissile black calcareous shale; prominent joints; *Lingulipora williamsana*	7.00
Limestone	1.00
Fissile black shale	0.25
Limestone and calcareous shale mixed	0.75
Calcareous black shale	0.10
Lower division; argillaceous shale, medium hard, non-fissile, greenish with black splotches	0.25
Gray to black earthy shale	0.25
Brown limestone	0.66
Gray to black shaly limestone	0.66
Brown limestone	0.66
Hamilton limestone	

Trousdale formation.—The Trousdale shale extends around the Cincinnati arch to Olympian Springs, where it pinches out, and extends south into Tennessee. It has a fairly uniform thickness of about 10 feet and varies lithically only in the thickness and number of enclosed calcareous and arenaceous lenses.

The Trousdale overlies the Portwood, where the Portwood is present, and Hamilton limestone elsewhere. It is overlain everywhere by the Blakiston formation, and, where the contact is within the black shale of the two formations, the boundary can be approximately located by the fossils in the Trousdale and can be determined

definitely when the joints of the two strata are exposed. At some places between Lebanon and Junction City the Trousdale closes with a thick bed of sandy black shale and calcareous lenses tossed together in a jumbled mass, and this character occurs in the Trousdale shale at Bransford, Tennessee (Section 36). From Estill County north the Olentangy shale, basal member of the Blakiston, rests on the Trousdale, and the contrast in color and the fossils in the Trousdale determine the boundary.

Schizobolus concentricus occurs through the entire thickness of the Trousdale and is common to abundant everywhere. *Orbiculoidea lodiensis* is rare at Harg.

The absence of *L. quadricostatum*, *Styliolina fissurella*, *Tentaculites gracilistriatus*, and *Chonetes lepidus* from the Trousdale in Kentucky, when they are all so abundant in the Blocher in Indiana, is noticeable. *Leiorhynchus* alone has been reported from Kentucky. *Schizobolus* is abundant in the Trousdale through Kentucky to the Ohio River at Louisville, but north of the river it occurs only in the basal 1 foot of the Blocher and is overlain by the *Leiorhynchus* zone. There is no evidence of a break in deposition between the two zones, and Genundewa and Rhinestreet species of conodonts occur below and above both zones in the Blocher.

The relation of the Portwood to the Trousdale is similar to the relation of the Trousdale to the Blocher; the *Schizobolus* and *Hypothyridina* zones are distinct, but no break in deposition is evident. Lithologically the change from the Duffin limestone to the Trousdale shale is sharply defined without a transition bed. The Harg shale can be distinguished readily, but the Trousdale shale and the Ravenna facies of black shale cannot be delimited. From all appearances deposition was continuous through the *Hypothyridina*, *Schizobolus*, and *Leiorhynchus* zones.

Savage (1930, p. 15) states regarding the Duffin:

> "At the base of the black New Albany shale formation there is present in most localities a single layer of somewhat sandy, dolomitic limestone, that on weathering presents a pseudo-brecciated appearance .... In a few places a band of black shale occurs below a layer of hard rock and layers of a limestone or dolomite similar in composition to the Duffin layer, and in some places carrying similar fossils, are imbedded with the black shale for a distance of 9 to 15 feet above the basal formation. These facts indicate that the basal sandy dolomitic Duffin layer belongs with the New Albany period of deposition, rather than with the underlying Middle Devonian limestone. Consequently it is here considered the basal layer of the New Albany formation"; and (p. 18) "because the basal Duffin layer is so similar on the east and west sides of the Cincinnati anticline in Kentucky and on account of the fact that at no locality in the state is there evidence of a hiatus within the formation, the New Albany formation is thought to represent a continuous succession of deposition during some part of Tully and Genesee time."

The writer did not recognize any member of the Portwood formation west of the geanticline. There is no continuous layer of limestone at the base of the New Albany outside the limits of the Duffin, but the Portwood as a whole is the basal stratum, and often a layer of limestone within the Harg or Ravenna occurs near the base of the black shale. Except at Rice Station, where he saw the calcareous shale, (the Harg shale in section 16), and regarded it as "an unusual and local element in the New Albany section" (p. 77), Savage failed to recognize the beds included in the Harg and Ravenna facies as coeval with the Duffin, or as distinct from the overlying Trousdale shale. Furthermore, his allocation of the Duffin to the base of the New Albany at all localities would place it at the base of the Harg and Ravenna shale. The Harg and Ravenna facies identify the Portwood with the New Albany, but the limestone

layers indicate a closer relation with the Middle Devonian than with the overlying portion of the New Albany; they represent the final deposition of bedded Devonian limestone. Savage's claim of a Tully-Genesee age for all the New Albany is not supported by the evidence presented in this paper.

G. A. Cooper (1942) united the Geneseo with the Tully and assigned them to the Taghanic stage of the Middle Devonian. His reason for including the Geneseo is based on a postulated disconformity at the top of the Geneseo, and the supposed occurrence of *Hypothyridina* in the Geneseo (Trousdale shale, *Schizobolus* zone) in Kentucky. *Hypothyridina* occurs in the underlying Portwood, not in the Trousdale, accordng to the observation of the writer. However, this fact does not invalidate the union of the two zones (to which the *Leiorhynchus* zone of the Blocher shale may be added), in a stage of apparently unbroken deposition of black shale. *Leiorhynchus* and *Schizobolus* occupy a single conodont zone in the Blocher, and *L. quadricostatum* has been reported with *Hypothyridina* in Kentucky. *L. limitare* in the Blocher is a faunal link with the Middle Devonian.

Blackiston formation.—The Blackiston retains its dual character and is divisible into two members composed of slightly different facies of black shale and a middle zone of gray shale, which interbeds with both members. The gray shale increases in thickness and number of layers from Crab Orchard northward, but from Crab Orchard south to Tennessee, where the outcrops are on the crest of the arch, the gray shale is irregular in occurrence and position within the Blackiston, and may be absent. Well records show gray shale in the New Albany east of the arch in south-central Kentucky but not to the west.

LOWER BLACKISTON MEMBER: The lower Blackiston is a stratum of homogeneous black shale with few distinguishing characters and contains layers of gray shale. The Olentangy shale is the basal bed of the lower Blackiston from Crab Orchard to central Ohio.

The Olentangy shale extends from Delaware Ohio (Sec. 30) to the Ohio River opposite Vanceburg, Kentucky (Sec. 31). Sections 24 and 25 by Morse and Foerste (1912) and sections 21, 20, 16, and 13, in the order given, show the extension of the Olentangy to Crab Orchard. The sections at Olympian Springs and Indian Fields are important links in tracing and determining its age. It overlaps Silurian beds from the Ohio River to Olympian Springs, the Portwood to Indian Fields, and the Trousdale to Crab Orchard. Its thickness is 17½ feet at Fox Springs, 8½ feet at Rice Station, and it pinches out at Crab Orchard. *Barroisella campbelli* and *Spathiocaris* at Indian Fields (Sec. 23) and its position above the Trousdale identify the Olentangy as Upper Devonian basal Blackiston.

The stratigraphic position, boundaries, lithology, fossil content, and geographic distribution from north to south, aside from the detailed tracing of the boundary beds around the Cincinnati dome, are evidence of the coevality of the Olentangy shale of Ohio and Kentucky and the *Spathiocaris* zone in the Delphi shale in northern Indiana and in the New Albany shale in southern Indiana. (*Cc.* sections 6, 5, 3, 1 and 30, 31, 24, 25, 23, 21, 20, 16, 13.)

Few fossils were collected from the lower Blackiston in the eastern area largely because the vertical sections are not favorable for collecting. The little plant

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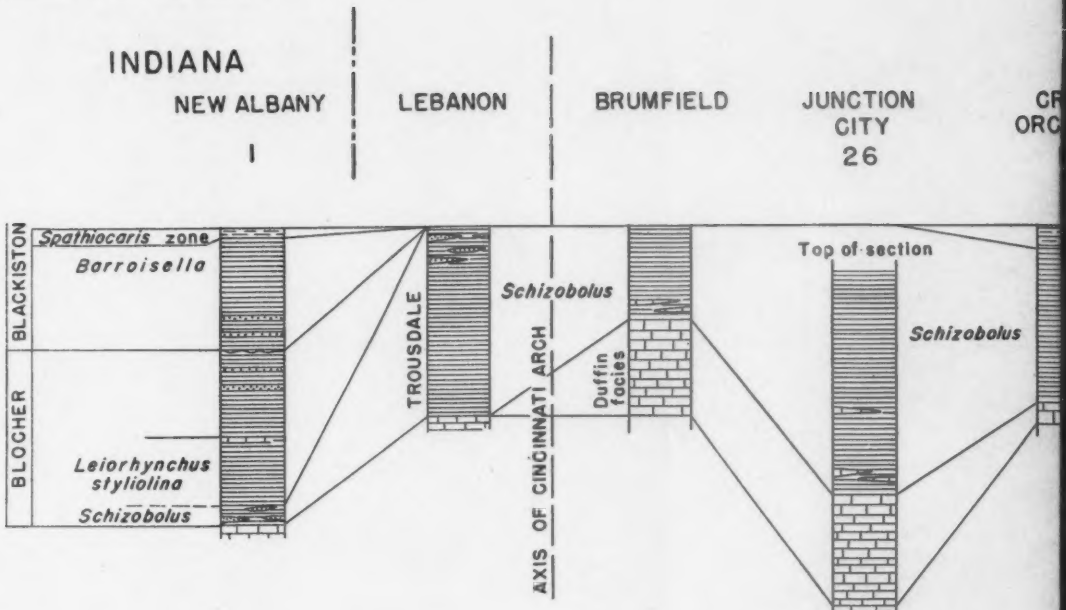
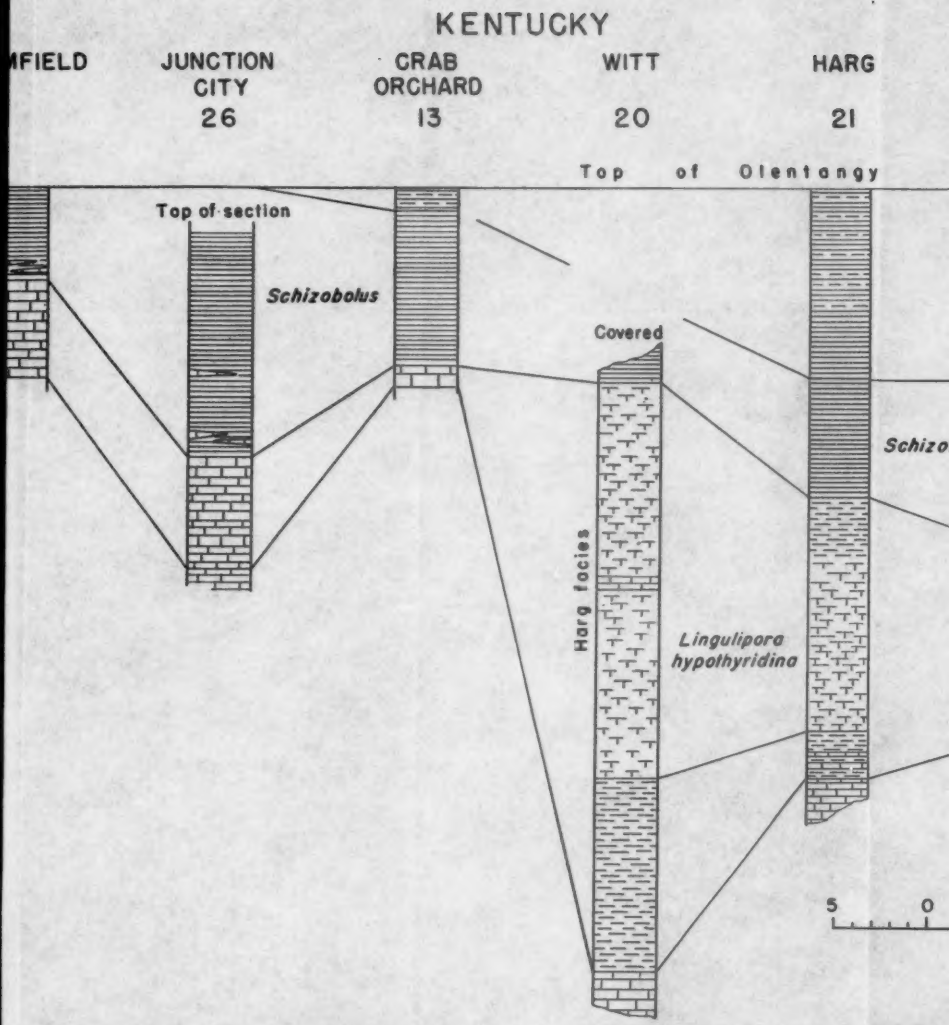
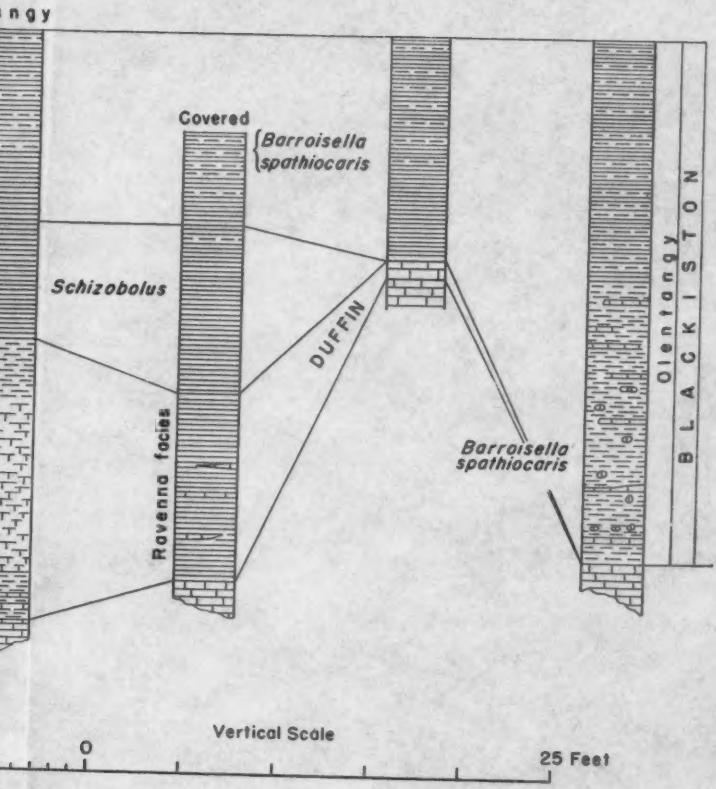


CORRELATION OF THE BASAL BEDS OF THE NEW



N OF THE BASAL BEDS OF THE NEW ALBANY SHALE IN INDIANA, KENTUCKY, A

ARG	INDIAN FIELDS	OLYMPIAN SPRINGS	OHIO DELAWARE
21	23	24	30



TUCKY, AND OHIO

Foerstia furcatum (Dawson) Hirmer is abundant near the water level along the creek north of Big Hill, Madison County, near the base of the Blackiston. As noted above *Barroisella campbelli* and *Spathiocaris* occur in the Olentangy at Indian Fields.

UPPER BLACKISTON MEMBER: The upper Blackiston—the Olmsted—shows a slight difference from the type New Albany, and the difference is largely in the appearance of weathered surfaces. The black shale of this member consists of alternate hard and less hard layers, but the difference in hardness is not so marked in fresh material; alternate layers weather to a soft debris, which accumulates at each layer, leaving the harder layers somewhat protruberant.

Layers of gray shale and thin lenses of lime with cone-in-cone are common in the upper Blackiston. The alternate hard and soft layers and the cone-in-cone are distinctive of the upper Blackiston in eastern Kentucky and Ohio, but have not been recognized west or south of Lincoln and Boyle County, Kentucky.

No fossils can be credited to the upper Blackiston outside of Indiana, and its identity in Kentucky depends on its lithology and position between the lower Blackiston and Sanderson. There is no evidence of wedging out or overlapping of any bed within this horizon. The conodont species in Indiana determine the relation of this member to the lower Blackiston and its Devonian affinities.

SECTION 22.—*On highway 15, 1½ miles east of Clay City, Powell County, Kentucky* (A continuous exposure for about 1 mile)

	FEET
Bedford	
Sandstone above, 2 feet; gray shale below, 2 feet	4.00
Sanderson formation	
Fissile black shale with abundant phosphatic nodules; *Lingula* cf *L. cuyahoga* at the bottom, *Lingula melie* at top	20.00
Upper Blackiston member, alternate hard and softer layers of black shale 2 to 4 inches thick, with layers of lime with cone-in-cone	25.00
Black shale interbedded with gray shale	8.00
Covered	

SECTION 23.—*A short distance north of highway 15, on a secondary road, at the Powell-Clark County line on Lulbegrud Creek near Indian Fields, Kentucky*

	FEET
Blackiston formation	
Olentangy shale, alternate layers of black and gray shale, *Barroisella campbelli* and *Spathiocaris* sp. in the gray shale, upper part covered	5.50
Trousdale formation, fissile black shale, *Schizobolus*	
Portwood formation	
Ravenna shale facies, fissile black shale with layers of limestone, *Lingulipora williamsana*	
Total thickness of Trousdale and Ravenna	19.00
Beechwood limestone	

SECTION 24.—*On west side of hill 1 mile west of Olympian Springs, Bath County, Kentucky* (Morse and Foerste, 1912, p. 37)

	FEET
Fissile black shale	93.00
"The lower part has some soft blue, argillaceous shale alternating with black shale and is suggestive of the Olentangy shale of central Ohio."	
Devonian limestone	
Layer of brownish limestone, Duffin layer	0.67
Two medium layers of brown limestone	1.00
Layer of brownish limestone with chert at top, *Ambocoelia umbonata* (Conrad) abundant	2.00
Crab Orchard shale	

The writer measured 12 feet of Olentangy shale at the base of the New Albany 2 miles west of Olympian Springs.

SECTION 25.—*At Fox Springs, 10 miles west of Flemingsburg, Fleming County, Kentucky* (Morse and Foerste, 1912, p. 27)

	FEET
Cuyahoga formation	
Sunbury shale	16.50
Bedford-Berea shale 18.50 feet, covered interval 14 feet	32.50
Ohio shale	
Black fissile shale. Probably none included in the covered interval above	172.00
[Olentangy shale]	
Soft, blue, argillaceous shales alternating with black shales	17.50
Crab Orchard shale (?)	

Sanderson formation.—The Sanderson shale is uniform in character from Indiana into Kentucky and from Lake Erie to Tennessee: it is a hard slaty, weather-resistant, fissile black shale with conodonts, small fish scales, small teeth, and large fish remains. *Lingula melie* Hall is common to abundant everywhere east of the geanticline. *Lingula* cf. *L. cuyahoga* Hall occurs at Irvine and Clay City. *Clepsidropsis chaneyi* Read and Campbell and *Steloxylon* sp. were collected at Berea; *Steloxylon irvingense* Read and Campbell at Irvine; *Archeopitys eastmani* Scott and Jeffrey at Brumfield, Boyle County. *C. chaneyi* occurs in the Sanderson in Indiana, and *A. eastmani* in the Falling Run at Junction City, Holy Cross, Pine Lick, and Boston, Kentucky, and New Albany, Indiana. C. L. Cooper (1936) collected *Angustidontus gracilis* Cooper from the top of the Ohio shale (Sanderson) in Rowan County, Kentucky, and from the Falling Run horizon at Boston, Nelson County, Kentucky. The species listed establish the continuity of the Sanderson through Kentucky and show a faunal break with the Blackiston.

In addition to the general description of the Sanderson given above, the character most noticeable in casual observation in east-central Kentucky, and the one that is definitely diagnostic, is the abundance of phosphatic concretions. They range from 2 to 4 inches in diameter, are disposed through the entire Sanderson, and are present at this level in every section from Rowan County southward but were not noticed north of Rowan County. They are identical in character with the nodules in the Falling Run.

The Sanderson overlies the Blackiston everywhere, and the joints and phosphatic nodules are guides to the boundary. Southwest of Irvine the Falling Run member of the Sanderson is present at the top of the Sanderson and is overlain by the New Providence, but from Irvine north through Ohio the Falling Run is absent and the Sanderson black shale is overlain by the Bedford shale.

FALLING RUN MEMBER: A layer of phosphatic nodules and a layer of gray shale overlie the Sanderson black shale in Kentucky, except north of Estill County. Heretofore this bed has been regarded as the basal layer of the New Providence, no doubt because of the similarity of the shale to the New Providence, but no fossils have ever been reported that would identify it with the New Providence. Interest in this bed centers at Junction City, Boyle County, where it is fossiliferous, and numerous species of plants and crustaceans have been described from Linietta Springs, a mile west of Junction City. The writer first determined by detailed tracing and by fossils

that the bed of nodules at Junction City is continuous with the Falling Run in Indiana and belongs to the New Albany period of sedimentation instead of with the New Providence; it is older than the Rockford limestone.

The Falling Run is overlain by the Underwood gray shale in Kentucky and Indiana west of the geanticline, but east of the geanticline the Falling Run nodules contact the New Providence. A layer of Bedford gray shale, which wedges in between the Sanderson black shale and the nodule layer, is a foot thick at Brumfield and Crab Orchard (Sec. 13), 6 inches thick at Junction City.

SECTION 26.—*At Linietta Springs, one mile west of Junction City, Kentucky.*

	FEET
New Providence	
Dark-gray shale	40.00
Dark-gray shale with yellow to olive-green mixture	2.50
New Albany	
Falling Run nodules, plants, brachiopods, crustaceans	0.25
Bedford gray shale, plants	0.50
Sanderson, black shale, many nodules	

Animal fossils may be collected from the Falling Run nodules at every outcrop; plant specimens occur in both the gray shale and the nodules, but mostly in the gray shale. However, they have been collected at only a few localities, where the ground levels off at the nodule bed and leaves an extensive surface covered with the remains of the Falling Run and gray shale. At most localities only the thin edge of the Falling Run and Bedford is exposed, and an enormous amount of excavating would be required to secure the few plants that might be present.

The following species occur at Junction City: *Calamopitys americana* Scott and Jeffrey, *Calamopitys foerstei* Read, *Diichnia kentuckiensis* Read, **Kalymma lirata* Read, *Kalymma resinosa* Read, *Kalymma grandis* Unger, *Kalymma auriculata* Read, *Calamopteris hippocrepis* Scott and Jeffrey, *Stenomelon muratum* Read, *Pliorachis danvillensis* Read and Campbell, **Periastron perforatum* Scott and Jeffrey, **Periastron reticulatum* Unger, **Archeopitys eastmani* Scott and Jeffrey, **Callixylon brownii* Read, **Arnoldella minuta* Read, *Clepsidropsis campbelli* Read, **Clepsidropsis titan* Read, *Stereopteris annularis* Scott and Jeffrey, *Microzygia lacunosa* Read, *Hierogamma jeffreyi* Read, **Pietschia polyupsilon* Read and Campbell, **Siderella scotti* Read, **Lepidodendron boylensis* Read, *Lepidodendron novalbanense* Read and Campbell, *Lepidostrobus kentuckiensis* Scott and Jeffrey, *Lycopogenia callicyrta* Read; *Lingula melie* Hall, *Lingula* cf. *L. cuyahoga* Hall, *Orbiculoidea herzeri* Hall and Clarke, *Colpocaris bradleyi* Meek, *Colpocaris elytroides* Meek, *Spathiocaris ulrichi* Cooper, *Spathiocaris williamsi* Ruedeman, *Solenocaris strigata* Meek, *Angustidontus seriatus* Cooper,[4] and many large fish remains.

The plants marked with an asterisk and all the animal species except *S. williamsi* and *S. ulrichi* are present in the Falling Run at New Albany, Indiana and establish the continuity of the beds of Indiana and Kentucky.

The Falling Run was traced to Big Hill, 4 miles east of Berea. Because of road conditions it was impossible to enter the region between Big Hill and Rice, a distance

[4] Reported by C. L. Cooper (1936).

of 8 miles, and little information is available regarding the top of the New Albany in that territory. However, a section by Stockdale extends the Falling Run across that region and within 2½ miles of Irvine.

SECTION 27.—*Two and one-half miles southeast of Irvine, Estill County, Kentucky*

	Feet
Exposed at north side of Louisville and Nashville Railway, immediately east of Cow Creek, at its confluence with the Kentucky River. (Stockdale, 1939, section 45.)	
New Providence formation (Boone Gap facies)	
Shale and siltstone	
Shale as above with phosphatic nodules in basal few inches	5.00
New Albany shale	
Shale fissile black, in abrupt contact with the clay shale above; exposed to the level of the Kentucky River	53.00

The phosphatic nodules representing the Falling Run in the base of the New Providence are evidently the same as those at Junction City and elsewhere.

Bedford, Berea, and Sunbury relations.—The Falling Run is absent north of Irvine, and the Bedford, Berea, and Sunbury occupy the interval between the Sanderson black shale and New Providence. Morse and Foerste (1912) traced the Bedford, Berea, and Sunbury from Lewis County to Estill County. Their sections show that south from Lewis County for 35 miles to Olympian Springs, Bath County, the Sunbury varies little from 15 feet in thickness, and the Bedford and Berea combined decrease from 95 feet to 13 feet. They were not able to identify the Berea with certainty south of Lewis County. The Sunbury and Bedford decrease in thickness, the Bedford irregularly, to Minerva Mountain, at Irvine where the Sunbury is 3 feet thick and the Bedford is 1½ feet or less. At Olympian Springs the thickness of the Bedford ranges from 2 inches to 12½ feet, and south to Irvine from 2 inches to 4 feet.

SECTION 28.—*On Minerva Mountain, Irvine, Estill County, Kentucky* (Morse and Foerste, 1912)

	Feet
Cuyahoga formation	total thickness 144.00
Lower layer of "soft bluish to pinkish argillaceous shales with small phosphatic nodules"	8.50
Sunbury shale	3.00
Bedford-Berea	
Argillaceous shale with phosphatic nodules	1/6
Black fissile carbonaceous shale	1/4
Dark argillaceous shales, with some carbonaceous material	1/2
Gray calcareous and argillaceous shale, slightly fossiliferous	1/6
Yellowish, calcareous and argillaceous shales, with upper part very fossiliferous	5/12
Ohio shale	94.50

Morse and Foerste (1912) listed species which Foerste had collected at Irvine and Indian Fields and classified as Bedford in age.

The varied composition of the Bedford is shown at Minerva Mountain. An outcrop with fossils in the Bedford, probably identical with the section of Morse and Foerste, may be found in the pathway that leads up Minerva Mountain from the street in east Irvine. In the pathway the Bedford is 1½ feet thick and contains fossils and a layer of phosphatic nodules; 75 feet west of the pathway, around the brow of the hill, the bed, a foot thick, contains a layer of nodules but no fossils; 60 feet east of the pathway the shale is absent, and the bed is represented only by a layer of nodules.

Lingula melie and *Orbiculoidea herzeri* occur in great abundance in a thin dense layer a few inches above the base of the Sunbury at Irvine, and it is reported that this is a character of the Sunbury at the type section at Cuyahoga Falls and elsewhere in Ohio. The Sunbury contains phosphatic nodules scattered through the bed and disposed in a layer near the top. At Olympian Springs, where the Sunbury begins to thin, a layer of nodules is present immediately above the Sunbury, and they become larger and more numerous to the south. From these overlying nodules *L. melie*, *O. herzeri*, and *Rhadinichthys* were collected in the vicinity of Irvine. The Bedford, Berea, and Sunbury occupy the interval between the black shale of the Sanderson and the New Providence north of Irvine; the Falling Run and the subjacent layer of gray shale occupy the same interval to the south. The three layers of nodules, one in the Bedford, one in the Sunbury, and one above the Sunbury, converge as the beds wedge out. The Falling Run nodules do not extend beneath the Bedford at Irvine. The layer of fossils indicates that the base of the Sunbury had the farthest extension, and the nodules indicate near-shore conditions bordering the Lexington dome during the final phases of the New Albany. Their location at the top of the Underwood, Bedford, and Sunbury indicate regression and imply emergence of the geanticline. The process continued from late Sanderson through Sunbury time and was localized around the Lexington dome.

Bedford formation.—The gray shale between the Falling Run nodules and the black shale of the Sanderson, east of the axis to Irvine, is identified as the Bedford formation. It represents an environment distinct from that of the Falling Run, which contains only black mud types of animal life. The plants common to the gray shale layer, the Underwood, and the Falling Run attest the close relations of the three layers; the gray shale at Junction City has the same lithology as the Bedford and Underwood.

Fissile black shale occurs in the Bedford at Irvine (Section 28) and at other localities in Kentucky. In a section on East Branch near Berea, Ohio, by Prosser (1912) two layers of black shale 5 and 11 feet thick, and a total thickness of 8 feet of gray shale with Bedford fossils, are interbedded within the limits of the Bedford assigned by Prosser. The top of the Cleveland could be placed at the top of the black shale. Swartz (1924; 1927) reported similar conditions in eastern Tennessee. The Olinger shale, which he correlated with the Bedford on the evidence of fossils at Apison and LaFollette, interbeds downward with the black shale, which he correlated with the Cleveland shale.

These conditions show that Bedford sedimentation began before the close of the Sanderson and that most of the Bedford was deposited subsequent to the Falling Run. This places the Bedford and Underwood in similar stratigraphic positions. G. A. Cooper (1942) correlated the Bedford with the Underwood, Hamburg, and Glen Park on the evidence of their closely related faunas, which he regarded as Devonian in age. Caster (1933) based a Mississippian age for the Bedford on the Mississippian stamp in most of the Bedford assemblage. By the classification presented in this paper the Bedford is Mississippian in age by virtue of its position above the Mississippian Sanderson formation.

Sunbury and Henryville relations.—The Berea and Sunbury follow the Bedford in

FIGURE 5.—*Correlation of the upper beds of the New Albany shale in Indiana and Kentucky*

Kentucky, and the Henryville follows the Underwood in Indiana. The Sunbury is 3 feet thick at Irvine and increases to 30 feet in Ohio; the Henryville is 1 foot thick at New Albany, Indiana, but its thickness toward the west is not known. There are no sediments that can be identified as Berea west of Irvine, although it may be represented in some of the nonfossiliferous nodules in the Falling Run. The Sunbury and Henryville contain fossils common to the Sanderson, and where the Underwood is absent black-shale life apparently continued without break from the Sanderson into the Henryville. The Sunbury and Henryville represent the final deposition of black shale in the two areas and are provisionally regarded as contemporaneous beds.

PHOSPHATE AND CARBONATE OF LIME IN THE NEW ALBANY SHALE

A limestone environment was prevalent in the area occupied by the New Albany during the Middle Devonian. Carbonate of lime occurs as beds in the Portwood formation and as concretions and thin lenses in the Trousdale and Blocher. Large calcareous concretions are common in the lower Blackiston in Ohio and the upper Blackiston in Indiana, and thin layers of lime and cone-in-cone characterize the upper Blackiston in Kentucky and Ohio. A pause in sedimentation at the close of the Blackiston was followed by the appearance of a new fauna and a change in the chemical balance of the sea, evidenced by the presence of concretionary phosphate of lime and the absence of carbonate of lime.

Scattered small phosphate concretions at the base of the Blackiston at one locality in Indiana and at one locality in southern Kentucky represent the only phosphate in any form noticed below the Sanderson in this area, and the phosphate below this horizon in Tennessee is not of the concretionary type. Phosphate in concretions occurs in the upper New Albany in Indiana, Kentucky, and the corresponding beds in Tennessee. No carbonate of lime is found in black shale above the Blackiston.

Concretions of phosphate of lime represent a Mississippian character in areas bordering the Cincinnati arch and occur in terminal facies of beds in the upper New Albany in all areas except Ohio, and in the Maury, New Providence, and Fort Payne of Tennessee. To what extent this character may be diagnostic of the Mississippian in other areas has not been determined.

NEW ALBANY SHALE IN OHIO

GENERAL STATEMENT

The Ohio beds, Olentangy to Sunbury, both inclusive, are represented in the New Albany. The lithologic characters ascribed to the beds in Kentucky apply to Ohio with few exceptions. Phosphatic nodules do not occur in the Sanderson in Ohio, and the large calcareous concretions, characteristic of the lower Blackiston in Ohio, were not observed south of Vanceburg, Kentucky. The beds have been given more study in Ohio than in other States, but there has been little unanimity of opinion as to their interrelations or classification. The terms Cleveland and Huron have been used very loosely at times, and the lower limit of the Cleveland and the upper limit of the Huron, as used by different workers, overlapped.

In this paper the lower Blackiston is limited to the lower stratum of the Ohio shale, which contains large calcareous concretions and intercalated layers of gray shale. The Sanderson is restricted to the upper stratum of uniformly hard black shale, which underlies the Bedford and is typically represented east of Cleveland. The upper Blackiston lies between the lower Blackiston and Sanderson and contains layers of black shale of different hardness, layers of gray shale, and lenses of limestone with cone-in-cone structure. When restricted to the same limits the Huron, Olmsted, and Cleveland are equivalent to the lower Blackiston, upper Blackiston, and Sanderson respectively. The top of the Sunbury is tentatively recognized as the top of the New Albany. The relations of the Bedford, Berea, and Sunbury to the New Albany, in Kentucky, satisfied the requirements of this paper, and they were given no further study in Ohio.

The two members of the Blackiston and Sanderson can be identified readily by their gross appearance in extensive outcrops. The Blackiston is prominent in outcrops across Ohio to Lake Erie. The isolated section at East Liberty, Logan County (Sec. 29), on top of the Cincinnati arch, shows the spread of sediments across the arch to Indiana. *Barroisella campbelli* and abundant *Sporangites* at East Liberty; *B. campbelli* and *Spathiocaris* sp. in the Olentangy at Delaware (Sec. 30); and the *Ancyrodella* group of conodont genera, reported from the Huron by Branson and Mehl (1933, p. 181), identify the lower Blackiston, and the large concretions determine its equivalency with the Huron.

OLENTANGY SHALE

The Olentangy shale is the orphan of the Ohio family. Winchell (1874) named the Olentangy and described the type section at Delaware (Sec. 30). Stauffer (1909, p. 27, 117) correlated the Olentangy of central Ohio with the Prout of northern Ohio, thus giving the Olentangy a Middle Devonian age. He stated that it extends to the Ohio River and probably into Kentucky. Lamborn (1927) traced a gray shale in southern Ohio to the Ohio River opposite Vanceburg, Kentucky (Sec. 31) and concluded that it belonged to the Olentangy of central Ohio. He regarded the Olentangy as the basal bed of the Huron and Upper Devonian in age and not a part of the Prout.

Barroisella campbelli and *Spathiocaris* sp. occur in the lower part of the Olentangy at Delaware and identify it as basal Blackiston. These species were collected by Dr. Lewis G. Westgate and are in the geological collection of Ohio Wesleyan University at Delaware.

It was shown in previous paragraphs that the Olentangy overlaps the Tully Portwood and the Geneseo Trousdale from Olympian Springs to Indian Fields, Kentucky. These overlap relations and *Barroisella* preclude the possibility of the Olentangy being part of the Prout.

A fine display of the upper Blackiston occurs at the junction of the East Branch and West Branch of Rocky River, near Olmsted, the type region of the Olmsted shale. The sections at this locality are illustrated as the Cleveland shale by Prosser (1912. Pl. xxiv, xxv). The weathering of the softer layers of black shale with collections of detritus at each layer is very conspicuous, layers of cone-in-cone are present, and gray shale occurs near the bottom of the section.

The softer black-shale layers and cone-in-cone of the upper Blackiston occur only each of the Cincinnati arch and north of Casey County, Kentucky. In Indiana, the gray-shale zone occupies only the lower quarter of the upper Blackiston, and black shale the remainder. The change of facies is abrupt, but there is no evidence of a break in deposition. In Kentucky and Ohio, the gray shale occurs in the basal portion of the upper Blackiston, and the hard and soft layers of black shale in the upper part. The writer regards the softer layers of black shale as the product of the blending of gray- and black-shale elements, the latter predominating.

The evidence for the age of the upper Blackiston in Ohio, as in Kentucky, depends on its stratigraphic relations with the lower Blackiston and Sanderson, and the age determined by conodonts in Indiana.

The recognition of the Olmsted as upper Blackiston and Devonian, not part of the Mississippian Sanderson, is an important step in determining the chronological relations of the Ohio beds. The confusion in the identification and classification of these beds that has prevailed involves the horizons assigned to many of the fossils of the Ohio shale and thus weakens the very basis of correlation.

The Sanderson is identified by its position beneath the Bedford and by its hard slaty character. The writer was able to delimit the Blackiston and Sanderson along Rocky River by means of the joints of the two beds (Sec. 32). Cushing (1931) lists *Lingula melie* Hall, *Orbiculoidea herzeri* Hall and Clarke, and *Spathiocaris williamsi* Ruedemann as characteristic species of the upper Cleveland. All occur in the Sanderson in Kentucky and Indiana and verify the extension of the Sanderson into Ohio and its Mississippian age.

SECTION 29.—*West of the quarry of the East Liberty Stone Company, East Liberty, Logan County, Ohio*

	FEET
Blackiston formation	
Poorly exposed decayed black shale	16.00
Black shale and gray shale alternating	10.00
Black shale, thick-bedded, jointed, many large concretions	10.00
Gray shale with concretions and *Barroisella campbelli* interbedded with black shale	16.00
Brownish-black shale rich in *Sporangites*	9.50
Devonian limestone	

SECTION 30.—*Salient features of the type section of the Olentangy shale at Delaware, Ohio, as given by Stauffer* (1909)

	FEET
Ohio shale with large spherical concretions	
Olentangy shale	
Soft blue argillaccus shale and thin layers of brown to black shale with flat limestone concretions, and a discontinuous layer of concretions near the top	13.33
Soft blue shale with lenses of limestone	4.80
Soft blue shale with layers of concretions to level of river	10.00

SECTION 31.—*At locality 18, near the Ohio River, in Adams County, Ohio (condensed)* (Lamborn, 1927, p. 715)

	FEET
Ohio shale, black carbonaceous shale	10.00
Olentangy shale	
Alternate layers of blue shale and black shale	13.20
Bluish-gray shales with many nodules of iron pyrite	8.80
Monroe dolomite	

SECTION 32.—*Along Rocky River in Rocky River Park west of Cleveland, Ohio*

Sanderson (Cleveland) shale, a hard slaty shale, blocky, with prominent vertical joints with plain faces.
Bed slightly overhanging.

Upper Blackiston (Olmsted) shale. Alternate layers of hard and less hard black shale, which respond to weathering unequally, the harder layers often extending in shelflike series. Layers of lime with cone-in-cone at various levels. Joints slightly oblique, faces somewhat uneven

Chagrin shale

NEW ALBANY AND CHAGRIN RELATIONS

The Devonian age of the Chagrin, the Erie of Newberry, has not been questioned, but its relation to the contiguous beds has always been controversial. The border of the shoreward facies of the Upper Devonian is irregular in its westward extension and relation to the New Albany belt of outcrop. In Tennessee there is a gradual shift of facies to the black shale,—but in northern Ohio a lobe of the Chagrin extends farther west, the change is more abrupt, and the transition zone is partly covered. The position of the Chagrin midway in the Ohio shales favors diversity of interpretation.

Newberry (1873) assigned the Huron and Erie to the Devonian and the Cleveland to the Waverly. He stated that the Cleveland has the greatest development around the mouth of the Cuyahoga River, and the upper Huron in the northern part of its range interbeds with the Erie. Cushing (1912) recognized two members of the Cleveland:—the upper, the true Cleveland, a black slaty shale, mostly very fissile; the lower, which he named Olmsted, with the characteristics herein ascribed to the upper Blackiston. He recognized an unconformity between the Cleveland (plus Olmsted) and Chagrin, which he regarded as the Devonian-Carboniferous boundary (1931). Ulrich (1911) introduced the Chattanoogan series which included the Huron, Olmsted, and Cleveland as lithological members of a diastrophically unbroken formation, which overlaps the Chagrin shale. He placed the lower Mississippian boundary between the Olentangy and Huron. Kindle (1912) opposed the overlap theory of Ulrich and regarded the Huron and Cleveland as equivalent to the Chagrin. He defined the Huron as the lower bed of the Ohio shale with large calcareous concretions, and the Cleveland as the bed containing cone-in-cone structure but no concretions. Prosser (1912) concluded that the Chagrin gray shale and sandstones are replaced westward by the black shale of the Huron and lower Cleveland and placed the lower Mississippian boundary between the Bedford and Berea.

These opinions summarize the points of difference in the long standing controversy over the age and relations of the divisions of the Ohio shales. The argument largely focuses on the relation of the upper Blackiston to the lower Blackiston as well as to the Chagrin. The Devonian-Mississippian boundary has been located at the base of the Huron, Cleveland, Bedford, and Berea.

The determination of the age of the individual beds eliminates some of the argument. The present classification furnishes a different point of view for consideration of the problem and throws the weight of evidence of the entire New Albany area into the Ohio shale problem.

The Upper Devonian age, facies pattern, and stratigraphic relations within the

same boundaries, of the Blackiston and Chagrin sequences, are evidence of their coevality. Prosser's (1912) sections given as evidence of the intergrading of the Chagrin and Cleveland occur west of Cleveland, and the particular portion of the Cleveland he regards as transition beds is part of the upper Blackiston. In addition to the gray shale zone Prosser cites as evidence of intergrading, the writer also would include the softer layers of black shale in all of the upper Blackiston. Thus the entire upper Blackiston (Olmsted or lower Cleveland of other workers) is equivalent to the upper Chagrin shale. The Sanderson overlaps both the Blackiston and Chagrin shale. The relation of the Sanderson to the Blackiston and Chagrin in Ohio conforms to the stratigraphic relations of the beds at this horizon in all of the New Albany area.

The systemic break between the Blackiston and Sanderson continues between the Chagrin and Sanderson. There is no break within the Blackiston or Chagrin that would sustain the claim of overlap of any part of the Blackiston on the Chagrin. The Sanderson thins from Cleveland eastward and disappears near the Ashtabula County line. Prosser's (1912) sections show interbedding of the black Cleveland shale and Bedford shale on East Branch, near Berea (p. 481); on Skinner's Run, in Cuyahoga Valley (p. 67); and near the eastern limit of the Cleveland in Geauga County. Evidently the Sanderson wedged out from the bottom upwards going east.

On the grounds that there is no basal conglomerate to show the overlap of any member of the Ohio shale on the Chagrin, Kindle (1912) objected to the overlap theory of Ulrich (1912). His objection also would apply to the overlap of the Sanderson on the Blackiston in all areas and on the Chagrin. Only in Tennessee, north and west of the Basin, in all of the New Albany area, is there a Mississippian basal conglomerate. Apparently the birth of a system in the New Albany black mud environment was not attended by the processes and basal conglomerate usually prescribed for such a world-wide change. The sea quietly departed, as quietly returned, and only the new life forms bear witness to its arrival.

CHATTANOOGA SHALE IN SOUTH-CENTRAL KENTUCKY

The New Albany crops out on the crest of the Cincinnati arch, and there are few exposures from Crab Orchard to the Tennessee boundary. The Trousdale is not always present, and the Blackiston does not show the normal development of the middle gray shale, but the Sanderson retains its lithologic characters.

The outcrops of the New Albany in the southern tier of counties in central Kentucky are adjacent to the outcrops of the Chattanooga shale in central Tennessee and are treated as a part of the Chattanooga.

SECTION 33.—*On highway 90, 2 miles west of Burkesville, Cumberland County, Kentucky*

	FEET
New Providence shale and limestone	
Maury shale with 3 courses of nodules	1.00
Chattanooga shale	
Gassaway formation, hard flaky black shale with nodules throughout, *Lingula melie*	7.00
Change of joints	
Dowelltown formation, black shale in layers ½–1 inch thick, separated by silty partings	14.50
Soft blue shale with red partings in upper part	1.00
?Soft bluish shale with yellowish limestone layers	3.00
Ordovician	

SECTION 34.—*On highway 90, 1½ miles west of Willow Shade, Metcalfe County, Kentucky*

	Feet
Hard gray limestone	
Maury shale and nodules, poorly exposed	
Chattanooga shale	
Hard black shale with *Lingula melie* near the top. Only the upper part is accessible for study	19.00
Impure black shale	0.50
Gray-black argillaceous shale with red partings	2.67
Black shale	2.75
Coarse sand, pyrite and iron oxide	0.50
Hard gray limestone	

SECTION 35.—*On Barren River between Barren and Allen County, Kentucky* (Butts, 1922).

	Feet
Fort Payne chert (limestone and chert)	
Chattanooga shale	
Shale, black, fissile, carrying *L. melie?*	33.00
Shale, black, highly fissile with *Schizobolus* and thin calcareous laminae	10.00
Devonian limestone	

Mr. Lucian Bechner, who has spent many years in oil-research work in Kentucky, reported to the writer that 1–2 feet of black shale overlies the Maury shale at some localities in Cumberland County.

Savage and Sutton (1931) reported a fossiliferous

> "cherty horizon in a limestone layer about 20 feet above the base and 2½ feet below the top of the black shale, along a tributary of Trace Creek in the southeastern corner of the Scottsville quadrangle less than a mile from the locality mentioned above [mouth of Dry Creek in Barren County] near the mouth of Rhodens Creek."

On the evidence of a fauna collected from the cherty horizon they correlated the bed with the Bushberg.

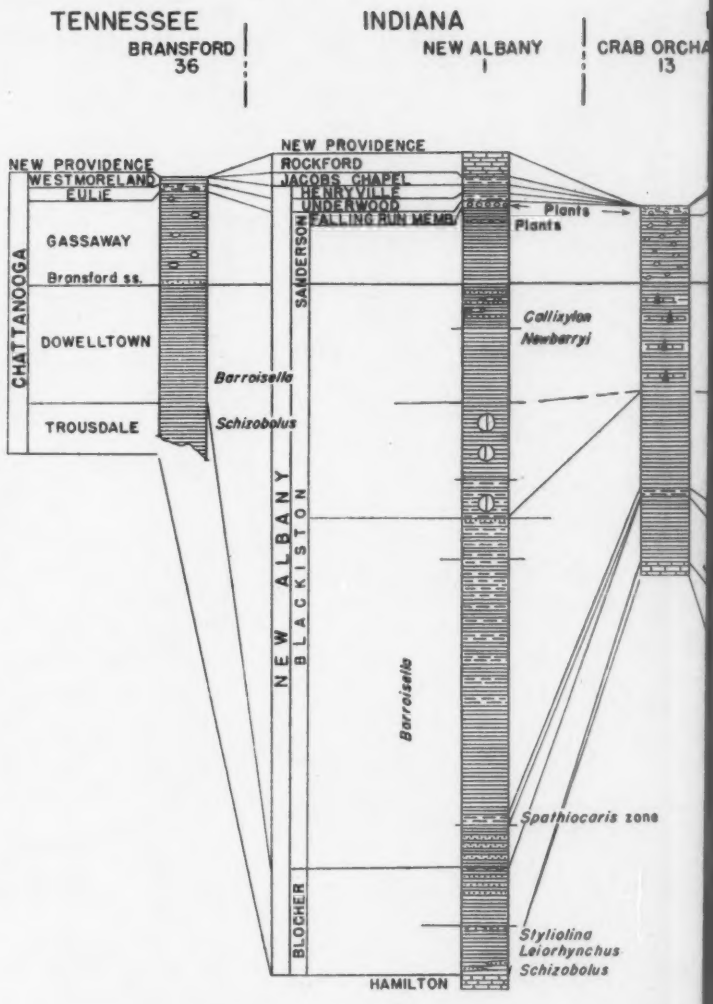
Savage (1930, p. 73–74) reported *Lingula spatulata*, *L.* cf. *L. ligea*, *Orbiculoidea* cf. *minuta*, *Roemerella grandis*, *Schizobolus concentrica*, and *Styliolina fissurella* from a concretionary shale 1 to 2 feet below the top, and 30 feet above the base, of the New Albany shale on Sulphur Creek in the southeast part of Cumberland County. The occurrence of these species at the horizon given by Savage is out of harmony with the conditions in the other sections given for this region and is not supported by any other reported section in Kentucky or in the bordering counties of Tennessee. The presence of these species at the horizon given needs verification.

CHATTANOOGA SHALE IN CENTRAL TENNESSEE

GENERAL STATEMENT

The belt of outcrop of the Chattanooga shale extends from Cumberland, Monroe, and Allen counties, Kentucky, through Clay, Macon, and Sumner counties, Tennessee; it encircles the Central Basin along the Highland Rim, and joins again from Lincoln to Hardin County, before entering Alabama, where it extends to Birmingham. It crops out in eastern Tennessee from Chattanooga to Cumberland Gap and along Clinch Mountain, extending into Virginia.

The name Chattanooga was given to the black shale in Tennessee by Hayes



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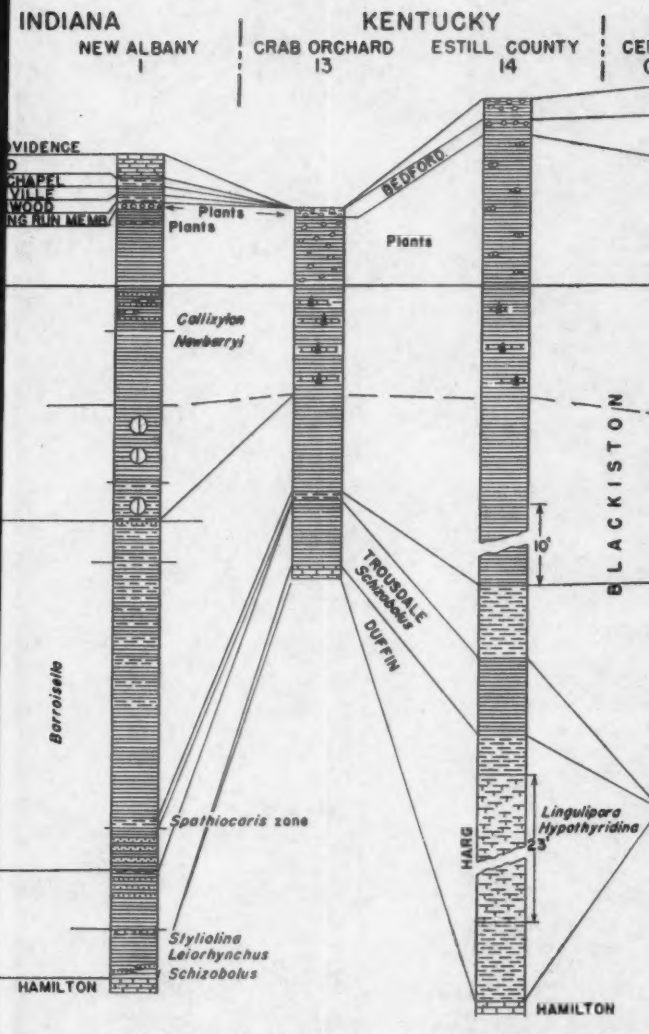

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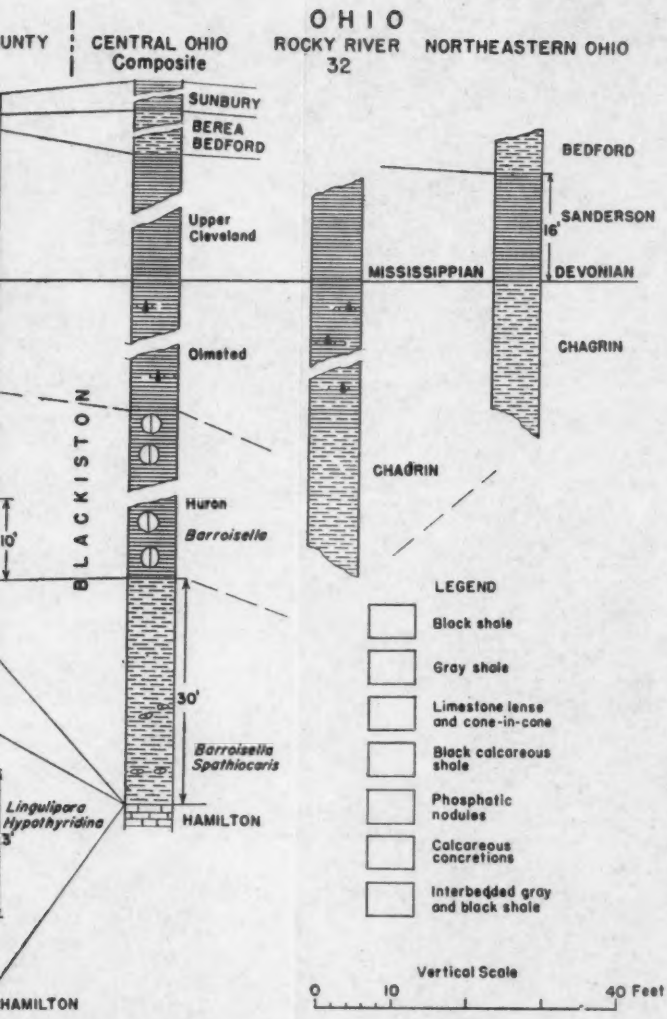

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(1892), and the type section was located at Chattanooga. The term has been used to refer to the black shale anywhere in Tennessee, but apparently the type section has been considered more typical for eastern Tennessee. Actually, the type Chattanooga is detached from both the shale of eastern Tennessee and that around the Central Basin and has not been correlated definitely with either. The Chattanooga is 20 to 35 feet thick in the Chattanooga district, but only about 10 feet is exposed in the type section on Cameron Hill; it is not a representative section for any region.

The Chattanooga shale of Tennessee has the same time limits as the New Albany shale in Indiana and Kentucky. All the divisions of the New Albany, their stratigraphic relations, and lithic characters are duplicated in the Chattanooga. There is no evidence of wedging out of any division below the Bedford between Indiana and Ohio and Tennessee. The terms New Albany and Chattanooga may be used interchangeably.

Names are proposed for the divisions of Chattanooga shale in Tennessee, and a comparison of the present classification of the New Albany and Chattanooga in the two areas follows:

Indiana	*Central Tennessee*
	Mississippian
	Fort Payne
New Providence	New Providence
	Maury shale (Fort Payne and New Providence)
Rockford	
Jacobs Chapel	
New Albany	Chattanooga
Henryville	Westmoreland
Underwood	Eulie
Sanderson	Gassaway
	Bransford ss. member
	Devonian
Blackiston	Dowelltown
Upper Blackiston	Upper Dowelltown
Lower Blackiston	Lower Dowelltown
	Hardin ss. member
Blocher	Trousdale

PREVIOUS WORK

The Chattanooga has been treated as all Devonian or all Mississippian with little reference to divisions within the group. Ulrich (1912) recognized only Cleveland or Sunbury time in Tennessee. Mather (1920) recognized two divisions of the black shale in the vicinity of Bransford: a lower division with a variable dip of 8°, which he classified as probably Devonian in age, separated from a horizontal upper division of Mississippian age by a conglomeratic sandstone containing fish remains, which he regarded as probably of Berea age. Pohl (1930) made three divisions of the Chattanooga in central Tennessee: (1) the lowest, locally present in the northern part of the State, he named Trousdale and correlated it with the Genesee-Portage; (2) a middle, Cleveland division, separated from (3) the upper, Sunbury division, by a persistent, pronounced unconformity that represents the Bedford-Berea interval,

FIGURE 6.—*Map of Central Tennessee north and east of the Central Basin*
Showing location of section

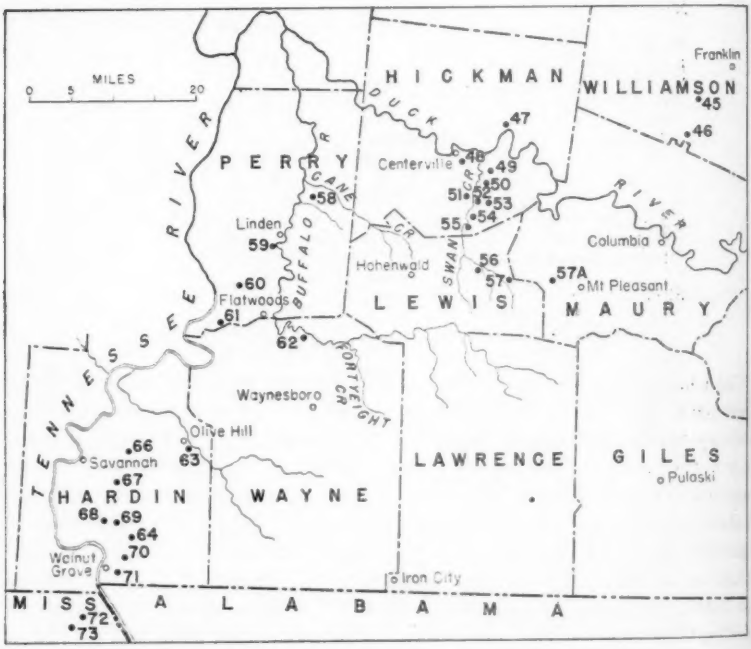

FIGURE 7.—*Map of Central Tennessee west of the Central Basin*
Showing location of section

according to Pohl. Pohl regards Mather's assignment of the lower unit of his dual division to the Devonian as erroneous.

A comparison of the divisions determined by Mather and Pohl with the present classification follows. The upper, Mississippian, division of Mather and the upper, Sunbury, division of Pohl are equivalents of the Gassaway. The conglomeratic sandstone, Berea?, of Mather is equivalent to the Bransford sandstone; and the erosional unconformity, Bedford-Berea interval, of Pohl is at the level of the Bransford sandstone. The lower division, late Devonian?, of Mather and the middle division, Cleveland, of Pohl are equivalents of the Dowelltown. The Trousdale of Pohl is in part equivalent to the Blocher. The Bedford and Berea are not present in central Tennessee except that they may be represented in the Eulie or Maury, nor is the Sunbury present unless it is represented in the Westmoreland or Maury. Pohl erred when he identified his middle division as Cleveland and Mississippian and criticized Mather's assignment of the bed at that horizon to the late Devonian.

DESCRIPTION OF FORMATIONS

Trousdale formation.—The Trousdale formation, identified by *Schizobolus*, occurs in Sumner (section 36) and Trousdale counties, Tennessee, and Allen County, Kentucky (section 35), and has not been reported south of this region in central Tennessee. It was named by Pohl (1930), who correlated it with the Genesee-Portage. The Trousdale overlies Middle Devonian limestone and underlies the *Barroisella* zone of the Chattanooga shale. The boundaries, lithology, and *Schizobolus* identify the bed in Kentucky with the basal portion of the Blocher in Indiana, and establish equivalent lower boundaries for the Chattanooga and New Albany.

Dowelltown formation.—The Dowelltown formation lies between the Trousdale and Gassaway shales and is the basal part of the Chattanooga in most of central Tennessee. The outcrop 1½ miles east of Dowelltown, DeKalb County, is selected as the type section. The thickness of the Dowelltown is 8 to 12 feet in Macon and Clay counties, 15 to 19 feet in Sumner County, 22 to 29 feet in DeKalb County, and 14 feet in Canon County.

East of the Central Basin, in DeKalb County and adjacent territory, the Dowelltown shows deposition under normal conditions for the formation and consists of a lower and an upper member, each with a lower bed of fissile black shale and an upper bed with interbedded layers of gray and black shale. The two members are delimited by *Barroisella* n.sp. and *Spathiocaris*, which occur in the lower member but not in the upper. This is in harmony with the characters of the Blackiston in Indiana.

At Celina and Red Boiling Springs the Chattanooga is a fissile black shale throughout, but the prominent joints indicate the boundaries of the three beds. Lithology and *Lingula melie* identify the upper bed as Gassaway, and *Barroisella* identifies the lower bed as lower Dowelltown. The middle bed is identified as upper Dowelltown by its lithology and the absence of fossils.

In the sections from Red Boiling Springs to Nashville, which lie near the crest of the Nashville Dome, the Dowelltown is a poorly fissile, soft, dull-black shale that shows a blending of the black and gray shale elements into a shale intermediate in

character. No lithic traits were observed at Bransford that would sharply delimit the two members, but *Barroisella* n.sp. occurs in the lower part of the stratum. At Bakers, the two members can be separated readily by lithology as described in section 43 and by the great abundance of *Barroisella* n.sp. in the lower member and its absence from the upper. The upper member is softer, nonfissile, sandy, and contains lenses of sandstone and many iron-oxide partings.

The lower member of the Dowelltown pinches out and is represented at Nashville only by a foot of sandstone. A layer of sandstone, which is correlated with the Hardin sandstone, occurs at the base of the Dowelltown at Celina, where it contains *Barroisella*, and at Red Boiling Springs.

Gassaway formation.—The Gassaway is a hard, slaty, fissile black shale with conspicuous joints, abundant *Lingula melie*, conodonts, and small fish scales. It contains phosphatic nodules at different levels, sometimes ranging through the entire formation. The only change in character from the Sanderson of Kentucky and Indiana is in the addition of a layer of sandstone at the base. The thickness of the Gassaway varies from 9 to 13½ feet north and east of the Basin, except in Macon County where it is 5 feet. Here the total thickness of the Chattanooga is only 13 feet.

BRANSFORD SANDSTONE MEMBER: A layer of sandstone occurs at the base of the Gassaway from Sumner County southwestward, and west of the Basin. The northernmost appearance of this sandstone is in the vicinity of Bransford. It occurs in an outcrop a mile south of South Tunnel on the Louisville and Nashville Railroad, north of Gallatin. It is 2–4 inches thick and contains many worn fish-bone fragments and conodonts at Bakers. The Bransford is 2 inches thick at Nashville and from there extends southward with the Gassaway shale, but without the underlying Dowelltown shale. At Hickman County, it enters the Swan Creek phosphate district and is represented by sandstone, conglomerate, or bedded phosphate. It is present at many places west of the Basin, and, since it is basal Gassaway and Mississippian, it is necessary to distinguish it from the Hardin sandstone, which is basal Dowelltown and Devonian. The name Bransford sandstone is proposed for this basal sandstone member of the Gassaway shale from its most northerly appearance at Bransford.

Mather (1920), in speaking of the dual division of a section of Chattanooga shale in the vicinity of Bransford, described the sandstone at the horizon of the Bransford as follows:

> "At the base of the upper, more resistant member there is a thin stratum which presents unusual features. This thin bed, ½ to 1 inch thick, is composed of dark brown or black sand grains and pebbles with numerous fragments of fossilized plant and animal organisms. Many of the sand grains and pebbles are phosphatic and the rock gives off a strong bituminous odor when broken. The larger pebbles approximate a quarter of an inch in diameter and some of them consist of brown stained quartz. Most of the quartz pebbles are well rounded and have evidently been transported a considerable distance. The bed presents all the characteristics of a residual deposit reworked and modified by waves and currents. The black shales above the conglomerate are horizontal; those below have a variable dip, which in one place attains a maximum of 8 degrees south."

The Bransford sandstone is at the horizon of a "persistent, pronounced unconformity" reported by Pohl (1930) and at the level of the marked faunal break between the Blackiston and Sanderson in Indiana and at the level of the lithic break between the Olmsted and Cleveland in Ohio.

Eulie and Westmoreland shales.—The Eulie and Westmoreland shales are complementary in their stratigraphic relations; the absence of either would make very difficult the determination of the status of the other. The Eulie is a soft, argillaceous shale in three gray, yellowish, or greenish layers, with a top layer of nodules at Bransford; it is a single layer of greenish shale with the nodules at the bottom, at Westmoreland. At Eulie, Sumner County, 5 miles east of Bransford, Swartz (1924) reported Hamburg oölite fossils from the Maury, and the shale at that locality is identified as the Eulie shale. The Eulie has been identified only at Bransford, Westmoreland, and Eulie, Tennessee. It overlies the Gassaway shale and is overlain by the Westmoreland.

The Westmoreland is a hard, fissile black shale, indistinguishable in lithology from the Gassaway, and contains scattered nodules at Westmoreland. There is nothing to distinguish it as a distinct bed of the Chattanooga besides its position above the Eulie shale. It is overlain by the New Providence.

The Eulie and Westmoreland shales in Tennessee; the "Maury" shale and overlying black shale in Cumberland County, Kentucky; the chert with Bushberg fossils and the overlying black shale in Allen County, Kentucky; the Underwood shale with Hamburg fossils and the Henryville shale in Indiana; and the Bedford and Sunbury shale in Ohio are closely related, if not identical, sequences. By this correlation the Eulie is the representative of the Bedford, and the Westmoreland the representative of the Sunbury, in Tennessee. The small disconnected tracts of these kindred beds at near-by localities in Tennessee and Kentucky indicate post-Chattanooga erosion, and the Westmoreland places a Sunbury time limit on the Chattanooga.

SECTION 36.—*Type section of the Bransford sandstone member.* At a bridge and along a small stream northwest of the bridge, along highway 31E, 2 miles north of Bransford, Sumner County, Tennessee

	FEET
Mississippian	
New Providence, alternate layers of bright-green shale and crinoidal limestone	
Chattanooga shale	
Westmoreland, fissile black shale	1.00
Eulie shale, upper layer of soft yellow shale, middle layer of hard gray shale, and lower layer of soft green shale with a layer of phosphatic nodules	0.75
Gassaway, hard, fissile black shale, prominently jointed	12.00
Bransford sandstone member	0.25
Devonian	
Dowelltown, medium-hard, poorly fissile black shale; *Barroisella* n.sp.	15.00
Trousdale	
Fissile black shale and sandy black shale with thin lenses of cross-laminated sandstone, all in an irregular undulating mass. The sandstone contains fragments of corals, crinoids, and other fossils. *Schizobolus* concentricus Vanuxem is rare and *Lingula spatulata* Vanuxem is abundant.....exposed	6.00

Bransford is the only locality known in Tennessee where all the divisions of the Chattanooga are present and exposed.

SECTION 37.—*Type section of the Westmoreland formation. Two hundred yards north of Garritt's Creek Church, north of Westmoreland, Sumner County, Tennessee*

	FEET
New Providence	
Chattanooga	
Westmoreland shale, fissile black shale with a few phosphatic nodules	0.50
Eulie shale, dark greenish-gray shale with a layer of nodules at the base	0.50
Gassaway, fissile black shale.....exposed	10.00

SECTION 38.—*Type section of the Dowelltown formation. One and one half miles east of Dowelltown, DeKalb County, Tennessee*

	FEET
Fort Payne	
New Providence? soft blue shale	5.00
Maury shale with phosphatic nodules in 3 or 4 courses, which are partly imbedded in the Gassaway	0.50
Chattanooga	
Gassaway, blocky, sheety, fissile black shale with a layer of nodules 1 foot from the top	6.00
Iron oxide parting	
Dowelltown	
Upper Dowelltown member, alternate layers, 2 to 3 inches thick, of fissile black shale and rusty gray shale	3.00
Black shale	4.00
Lower Dowelltown member, layers of argillaceous shale containing *Spathiocaris* sp. and worm borings alternating with impure fissile black shale containing *Spathiocaris* sp., *Barroisella* n.sp., plant impressions, and worm borings	12.00
Fissile black shale with abundant *Spathiocaris* sp.	10.00
Ordovician	

SECTION 39.—*On highway 26, 5.8 miles east of Smithville, DeKalb County, Tennessee*

	FEET
Fort Payne	
New Providence?, yellowish clay shale with an occassional phosphatic nodule	1.33
Maury shale, black earthy, pyritic mass with many disc-shaped pellets and phosphatic nodules	0.50
Chattanooga shale	
Gassaway shale, jointed, blocky, fissile black shale	6.33
Dowelltown shale	
Upper Dowelltown member, alternate layers of fissile black shale and the predominating impure gray shale in layers 1 to 8 inches thick	7.50
Fissile black shale, jointed	2.67
Lower Dowelltown member, alternate layers of gray and black shale, the gray predominating and increasing toward the top	11.00
Fissile black shale, jointed, blocky; *Barroisella* n.sp., *Spathiocaris* sp.	5.67
Ordovician	

A similar section occurs 7.5 miles east of Smithville on highway 26 in which the Chattanooga differs only in the relative thickness of the beds. The Maury is represented by 8 inches of decayed earthy limonitic material with abundant phosphatic nodules. The Maury is overlain by the New Providence laminated, soft, greenish shale, and Fort Payne chert. Another similar section occurs on highway 70, east of Carthage, Smith County, near the Smith-Putnam County line. The Maury is a gray shale with three or four courses of nodules, and the New Providence is a soft blue shale 3 feet thick.

SECTION 40.—*Type section of the Gassaway formation. On highway 53, 5 miles south of Gassaway, Cannon County, Tennessee*

	FEET
Fort Payne, greenish shale, lower 1 foot dark gray	8.00
Maury, brown limonitic material	0.50
Chattanooga	
Gassaway shale, jointed, hard, fissile black shale, abundant conodonts	12.00
Dowelltown shale	
Upper Dowelltown member, lumpy, greenish shale, a harder layer at top, with thin black shale partings	5.00
Softer black shale	2.00
Lower Dowelltown member, alternate layers of clay shale and black shale of about equal thickness	2.00
Fissile black shale	5.00
Limestone	

SECTION 41.—*Along highway 56, 4 miles south of Celina, Clay County, Tennessee*

	Feet
New Providence?, greenish-gray shale	2.00
Maury shale	0.50
Chattanooga shale	
Gassaway shale, hard, brittle black shale, prominent joints, phosphatic nodules in upper part; *Lingula melie*	12.00
Dowelltown shale, crumbly black shale	2.00
Fissile black shale, *Barroisella* n.sp. exposed	4.00

SECTION 42.—*Along highway 52, 8 miles west of Red Boiling Springs, Macon County, Tennessee*

	Feet
New Providence, soft blue shale with scattered nodules which are more frequent near the top	1.33
Maury, abundant nodules in 3 courses in a rusty gray shale	0.50
Semi-fissile bluish shale slightly carbonaceous	0.50
Chattanooga shale	
Gassaway shale, fissile black shale, scattered nodules in upper 1 foot; *Lingula melie*	5.00
Change of joints	
Dowelltown shale	
Fissile black shale	5.00
Change of joints	
Fissile black shale with abundant *Barroisella* n.sp.	3.00
Hardin sandstone member, *Barroisella* n.sp.	0.17
Ordovician	

One mile west of this locality an almost identical section differs only in the presence of a layer of nodules at the base of the Gassaway and no nodules in the Maury.

SECTION 43.—*At Bakers, Davidson County, Tennessee, a station on the Louisville and Nashville railroad*

	Feet
Ridgetop shale	
Maury shale, hard greenish shale with nodules, softer and slightly carbonaceous below	1.50
Chattanooga shale	
Gassaway shale, blocky, hard, brittle, thinly-fissile black shale; *Lingula melie*	10.00
Bransford sandstone member, a conglomeratic sandstone with worn fish fragments and a great abundance of conodonts	0.25
Dowelltown shale	
Upper Dowelltown member, soft, non-fissile, rusty-black shale in layers about ½ inch thick; many iron-oxide partings and sandy lenses; weathers to small chips	4.50
Lower Dowelltown member, very poorly fissile black shale with prominent joints; *Barroisella* n.sp. abundant	8.50
Layer of sandstone	0.10
Soft, poorly fissile black shale with abundant *Barroisella* n.sp.	6.00
Silurian shale	

SECTION 44.—*Ten Miles west of Nashville, Tennessee, along a concrete road, 1 mile west of its junction with the Old Charlotte pike*

	Feet
New Providence	
Soft, light-green shale	
Maury, hard, dark-green, sandy argillaceous shale	0.50
Layer of abundant nodules	0.25
Soft, green shale	0.50
Chattanooga shale	
Gassaway shale, sheety, fissile black shale, jointed	13.00
Bransford sandstone member	0.17
Dowelltown shale, poorly fissile sandy black shale which weathers to chips; thin lenses of sandstone	3.50
Hardin sandstone member, two layers of sandstone with black shale parting	1.00
Silurian shale	

CHATTANOOGA SHALE WEST OF CENTRAL BASIN

General discussion and sections.—When the Chattanooga is regarded as a stratum of black shale with the Hardin sandstone as the basal, and the Maury shale as the summit bed, all Devonian or all Mississippian, as has been the usual procedure, the sections at most localities are automatically correlated. However, the recognition of the Dowelltown and Gassaway formations, each with a basal sandstone member, and the recognition of the Kinderhook and Osage age of beds within the Maury complicate the stratigraphy. It also makes difficult the classification of the sections of nondeposition and erosion west of the Basin, where different members of the Chattanooga assumed similar arenaceous and/or phosphatic facies, which camouflage their identity.

The field work of the writer yielded a general idea of the Chattanooga stratigraphy west of the Basin, and the reports of Hayes, Dunbar, Jewell, Miser, and Bassler have been used freely for details.

The Chattanooga outcrops west of the Basin follow the crest of the Nashville Dome. The highest area during Chattanooga time centered in Lewis County. If a circle with a radius of 25 miles be drawn with Hohenwald as the center, it will include Lewis County and parts of the bordering counties—Perry, Wayne, Lawrence, Maury, and Hickman. This area was the comparatively flat top of the Nashville Dome, partly slightly emerged and partly slightly submerged, over which the Chattanooga did not exceed 8 to 10 feet in thickness on the periphery of the area. All members feathered out from all directions toward Hohenwald, except the Maury, which covered the whole area. This area includes the Swan Creek phosphate district on the east and the Perry County phosphate district on the west.

The Gassaway shale with its basal Bransford sandstone member, and the overlying Maury shale continued to the south from Nashville, then southwest to Hickman County, where the outcrop belt splits and goes around the Hohenwald "high", the east wing extending along Swan Creek, the west wing through Perry County and south. From Duck River along Swan Creek the black shale thins rapidly and pinches out at the Hickman-Lewis County line. The Bransford sandstone merges with and is partly replaced by the Swan Creek blue-black phosphate and continues as a sandy or conglomeratic phosphate, accompanied by the Maury, to the headwaters of Swan Creek in Lewis and Maury counties, with only a few traces of black shale. Thin sandstone underlying the phosphate bed at some localities between Nashville and Maury County are the only representatives of the Dowelltown shale present.

SECTION 45.—*Along Leipers Creek 2½ to 3 miles north of Water Valley, Williamson County, Tennessee.* (Bassler, 1932, p. 116)

	Feet
Chattanooga	
Typical black shale with 4 inches of kidney concretions at top	5.30
Conglomeratic blue phosphate	0.30
Ferruginous yellow shale	1.30
Silurian	

SECTION 46.—*On south side of hill, 2 miles southeast of Southall, Williamson County, Tennessee.* (Bassler, 1932, p. 126)

	Feet
Ridgetop	
Light green shale with phosphatic nodules	2.00
Chattanooga shale	
Black fissile shale with conodonts	13.00
Sandy phosphate	0.33
Silurian	

SECTION 47.—*Along Morgan's Branch, 2 miles north of Totty's Bend, Duck River, Hickman County, Tennessee.* (Bassler, 1932, p. 141)

	Feet
Fort Payne	
Maury shale	
Green shale with phosphatic nodules in upper part	0.50
Chattanooga shale	
Black fissile shale	5.00
Sandy beds with clay seams crowded with conodonts, *Cycloras*, and fish remains	0.50
Blue-gray phosphate composed of *Cycloras* and fragmentary fossils bedded and splitting into thin layers	1.00
Ordovician	
Leipers formation. Phosphatic limestone and brown phosphate	

The foregoing sections extend the Chattanooga to Lewis County. The following sections representing the Chattanooga along Swan Creek, from north to south, are compiled from figured sections by Hayes (1895–1896) with his section numbers given in parentheses. All sections are overlain by the Maury shale and Ridgetop shale, and all overlie limestone.

SECTION 48.—*At Centerville.* (Hayes, section 4)

	Feet
Black shale	10.00
Bedded phosphate	1.00
Sandstone	1.25

SECTION 49. *On Buck Creek.* (Hayes, sec. 16)

	Feet
Black shale	0 to 2.50
Coarse conglomerate	1.66
Compact phosphate	2.00

SECTION 50.—*On Blue Buck Creek.* (Hayes, sec. 17)

Black shale	1.50
Sandy and compact phosphate	1.50

SECTION 51.—*On Simmons Branch.* (Hayes, sec. 12)

Black shale	2.50
Sandy and shaly phosphate	2.50

SECTION 52.—*On Falls Branch.* (Hayes, sec. 19)

Black shale with beds of phosphatic nodules	9.00
Oölitic phosphate	1.50

SECTION 53.—*On Falls Branch.* (Hayes, sec. 20)

Black shale with phosphatic nodules	2.50
Oölitic phosphate with conglomeratic streaks	2 to 3.50

SECTION 54.—*On Swan Creek.* (Hayes, sec. 23)

	Feet
Black shale	1.00
Sandy and conglomeratic phosphate	2.00

SECTION 55.—*On Swan Creek.* (Hayes, sec. 24)

Black shale	0.75
Sandstone	2.00

SECTION 56.—*On Swan Creek.* (Hayes, sec. 27)

Oölitic and compact phosphate	3.00
Sandstone	1.00

SECTION 57.—*On Swan Creek.* (Hayes, sec. 34)

Sandy and shaly phosphate	2.00

SECTION 57a.—*On hill 4 miles west of Mount Pleasant, Tennessee.* (Bassler, 1932, p. 141)

	Feet
Mississippian	
Ridgetop shale, blue-gray shale	
Maury green shale with kidney phosphate bed	0.50
Chattanooga shale. Represented only by a blue to black phosphate bed with a thin phosphatic shale at the base	1.50
Silurian	
Niagaran limestone	0.20
Ordovician	
Leipers formation. Phosphatic limestone.	

The Maury, Gassaway, and Bransford enter Perry County along Brush Creek and extend through Perry, Wayne, and Hardin County into Alabama and Mississippi. The following representative sections, extending across Perry County from Brush Creek to Peters Landing on the Tennessee River, are compiled from figured sections by Hayes (1895–1896) and are given his numbers. The Maury and Ridgetop overlie all.

SECTION 58.—*On Brush Creek* (Hayes, section 38)

	Feet
Black shale	5.16
Conglomerate	0.67
Shaly phosphate	1.67
Hardin sandstone	0.40

SECTION 59.—*At Linden* (Hayes, sec. 40)

	Feet
Black shale	2.80
Conglomerate	0.50
Shaly phosphate	1.17
Hardin sandstone	3.33

SECTION 60.—*On Marberry Hollow* (Hayes, sec. 47)

	Feet
Black shale	2.80
Conglomerate	0.50
Shaly phosphate	2.50

SECTION 61.—*On Short Creek* (Hayes, sec. 49)

	Feet
Black shale	2.40
Shaly phosphate	1.33
Sandstone and phosphate	0.20
Hardin sandstone	5.25

SECTION 62.—*On Choat Branch, south of Buffalo River, east of Flat Woods, Wayne County* (Hayes, sec. 51)

	FEET
Ridgetop shale	
Sandy phosphate	0.33
Shaly phosphate	1.00
Hardin sandstone	5.33

In sections 58 to 62 the shaly phosphate and underlying beds are identified as facies of the Hardin and as basal Dowelltown, the conglomerate as Bransford, and the black shale as Gassaway.

Remnants of the Chattanooga representing the full sequence of beds have been preserved from erosion in a narrow belt extending through Hardin County into Mississippi. Dunbar (1919, p. 119) states that the Devonian rocks on Indian Creek, near Olive Hill, Hardin County, owe their preservation to the west limb of a large syncline. It is probable that this syncline also determined to some extent the deposition of the Chattanooga members in that territory.

SECTION 63.—*On Indian Creek in the vicinity of Olive Hill, Hardin County, Tennessee* (Jewell, 1931, p. 75)

	FEET
Ridgetop	
Chattanooga	
Phosphatic nodules	0.25
Black shale, more slabby than below	15.00
Black shale, grades through sandy shale and sandstone into the Hardin sandstone	10.00
Hardin sandstone	15.00

SECTION 64.—*Three-eighths of a mile east of Lowryville, Hardin County, Tennessee* (Jewell, 1931, p. 74)

	FEET
Cretaceous	
Chattanooga	
Black shale, slabby and pyritic	7.00
Persistent layer of sandstone	1.00
Black shale, platy and extremely fissile	8.00

Jewell (1931, p. 30, 39, 73) states that the Chattanooga black shale overlain by the Maury occurs just west of Lowryville, and that the Hardin sandstone is 10 feet thick east of Lowryville. Miser (1921, p. 23) states that the Chattanooga has a maximum thickness of 22 feet, and the Hardin sandstone 15 feet, in the Waynesboro quadrangle.

Morse (1928) describes the Whetstone Branch formation in Tishomingo County, Mississippi (section 73), which joins Hardin County, Tennessee, on the south, as a black shale with a few, mostly thin, sandstones. At places it includes a sandstone with a conglomeratic base. On the evidence of fossils, among which are *Tentaculites*, and its unconformable relations with adjacent formations of definite age, he referred the Whetstone Branch formation to the Devonian.

The sections given in foregoing pages show the extension of the Gassaway and Bransford from Sumner County to Perry County. In Perry County the Gassaway and basal Bransford sandstone overlap the shaly phosphate, which grades down into the Hardin sandstone (sections 58–61). The Hardin sandstone grades up into the lower black shale in the Olive Hill region, and they must be of the same age.

The lower black shale at Olive Hill and Lowryville is identified as the Dowel town shale and the Hardin sandstone as its basal member. The upper bed of black shale

is identified as the Gassaway shale, the middle sandstone as the Bransford, and the two beds of black shale and middle sandstone in the Whetstone Branch formation are regarded as Dowelltown, Bransford, and Gassaway.

Safford (1869, p. 317) gives a section near Clifton, northwest Wayne County, containing "eight feet at the base, interstratified with thin, smooth, fine-grained sandstone, containing individuals of *Lingula* (*Barroisella*) *subspatulata*? Meek and Worthen," which is underlain by 8 feet of "fine-grained sandstone highly charged with the same *Lingula* as above." These characters indicate the Hardin and Dowelltown horizons.

Hardin sandstone.—The Hardin sandstone, basal Dowelltown member, is fine-grained, gray to black weathering yellow or brown. It reaches a maximum thickness of 16 feet in the vicinity of Olive Hill and from there thins in all directions. Its thickness is 2 feet at Iron City, southwest Lawrence County, 1 to 3 feet in southern Hardin County, and 1½ to 3 feet along the Tennessee River. It is 7 to 10 feet thick northward from Olive Hill to near the Wayne-Perry County line and eastward to Forty Eight Creek. Near the county line and at Forty Eight Creek it abruptly thins and beyond these limits (between the Buffalo River and the Tennessee River, in Perry County) is 4 to 2 feet thick, thinning northward; along Cane Creek east of Linden in Perry County, and along Buffalo River and its tributaries in Lawrence County, it is thin or absent. Where the Hardin sandstone has been certainly identified a conglomeratic base has never been mentioned. This is the Hardin sandstone of Safford in its type area.

Shaly phosphate.—The shaly phosphate in Perry County overlies, grades into, and is coextensive in distribution with the "thin" Hardin and ends just south of Buffalo River in Wayne County, where the Hardin abruptly thickens to 7 to 10 feet. The combined thickness of the shaly phosphate and the "thin" Hardin at Buffalo River approximates the thickness of the Hardin south of the river and restores the uniform gradient of the upper surface of the Hardin from Olive Hill to Cane Creek.

Hayes (1895–1896) states that the shaly phosphate

> "frequently passes into a gray quartzitic sandstone similar to that which almost invariably underlies it. It rarely contains phosphatic ovules or casts, although *Lingulas* are very abundant on the partings between the layers."

Swan Creek and Perry County phosphates.—The different varieties of Swan Creek phosphate and Perry County phosphate have been regarded as facies of the Hardin sandstone. Bassler (1932, p. 139) states that:

> "in different parts of the Basin the introductory beds of the Chattanooga shale are represented by either the Hardin sandstone, or a conglomerate, or a blue-black phosphate, all being different phases of deposition, the difference being due to the source of material. The Hardin sandstone and the rocks correlated with it represent, therefore, a true basal deposit of a widely transgressing formation—its age, moreover, varying according to the stage of the overlap."

Hayes and Ulrich (1905) thought the

> "black phosphate, the conglomerate, and the fine sandstone are merely three phases of the same member and represent deposition during approximately the same time, their difference in composition being due to the difference in the sources from which the materials were derived."

Hayes (1895–1896) gave an extensive report on the Tennessee phosphates in which he presented 54 sections in the phosphate districts. He classified the Hardin sandstone, phosphate, black shale, and nodular shale (Maury) as Devonian. He described the varieties of phosphate as: oölitic, composed of small rounded or flattened ovules and coiled shells imbedded in a fine-grained or structureless matrix; compact, composed of ovules or coiled shells without the amorphous or granular ground mass; conglomeratic, composed of ovules, sand grains, and coarse pebbles and associated with or replacing the bedded varieties; and shaly, with the appearance of a fine-grained shaly sandstone.

These varieties occur in various combinations as illustrated in sections 48 to 57, but each variety is limited to a fairly small area; the compact and oölitic phosphates predominate on Swan Creek, and the shaly phosphate alone is present in, and covers much of, Perry County. The varieties follow a definite chronological succession, however, which was determined after plotting all available sections.

The sequence of the Chattanooga beds is as follows:

Perry County district	*Swan Creek district*
Maury shale	Maury shale
Black shale	Black shale
Conglomerate, sandstone, or conglomeratic sandstone	Conglomerate, sandstone, or conglomeratic sandstone
	Bedded phosphate: compact, oölitic, compact and oölitic, or conglomeratic
Shaly phosphate	Sandy and shaly phosphate
Sandstone (Hardin)	Sandstone

The sandstone or shaly phosphate, where present in the Swan Creek district, underlies the bedded phosphate; the bedded phosphate always underlies black shale or sandy or conglomeratic phosphate, or merges with the conglomerate. It was shown above that the shaly phosphate in Perry County grades into and is a facies of the Hardin sandstone, which is the basal Dowelltown member, and that the shaly phosphate is overlain by the basal Bransford, which is a sandstone, conglomerate, or conglomeratic sandstone.

In the Swan Creek district the Bransford sandstone, conglomerate, or conglomeratic sandstone is overlain by the Gassaway shale and overlies or merges with the black bedded phosphate. This bedded phosphate is the Chattanooga basal bed at most places along Swan Creek, but at a few localities it is underlain by a shaly phosphate or a sandstone, which have the characteristics of the shaly phosphate and Hardin sandstone of Perry County. The bedded phosphate is distinct from the underlying shaly phosphate and sandstone and grades into the overlying Bransford. For this reason the varieties of black bedded phosphate are classified as facies of the basal Mississippian Gassaway sandstone. The basal shaly phosphate and sandstone in the Swan Creek area are regarded as equivalents of the shaly phosphate and Hardin sandstone of Perry County, and are Dowelltown and Devonian in age.

"Early Mississippian" conodonts of Tennessee and Alabama.—Ulrich and Bassler (1926) described 60 species of conodonts collected at "Mount Pleasant, Tennessee, in the Hardin sandstone, a thin more or less phosphatic basal sandstone forming the introductory member of the Mississippian Chattanooga black shale in central

Tennessee." (p. 3). Probably the locality is the same as that of section 57a, and the bed is continuous with the phosphate bed.

Palmatodella delicatula, Palmatolepis perlobata, Polygnathus rhomboidea, Polygnathus concentrica, Ancyrognathus asymmetrica, Ancyrognathus bifurcata, and *Lonchodina discreta* are common to the Devonian Blackiston; and *Bryantodus subbrevis* and *Bryantodus pergracilis* are common to the Mississippian Sanderson of Indiana.

Holmes (1928) described conodonts from the Chattanooga shale of Alabama as Early Mississippian species. Eleven species are common to the Blackiston of Indiana, and 5 to the Sanderson. In the treatment of the stratigraphy of the Chattanooga of Alabama the Chattanooga is assigned to the Devonian Dowelltown and the Mississippian Gassaway.

The Mississippian age of the Chattanooga conodonts was founded by Ulrich and Bassler partly on their failure to find a single Devonian species in beds Mississippian in age; the Mississippian beds included the Ohio shale whose age has always been highly controversial. Huddle's work on the New Albany shale conodonts does not confirm the strict range limits of Devonian species, and the present stratigraphic work does not confirm the Mississippian age of all the Ohio shale. In Huddle's list of New Albany conodonts 20 Devonian species (11 from the Blackiston, 5 from the Blocher, and 8 from the Rhinestreet) occur in the Mississippian upper New Albany. The unusual procedure of establishing the standard Mississippian conodont assemblage in Tennessee, based on a standard Mississippian lithologic section in a group of doubtful age in Ohio, has not been convincing.

The pronounced break at the base of the Huron in Ohio, the Blackiston in Indiana, and the Hardin sandstone in Tennessee was selected by Ulrich (1911) as the lower limit of a new Mississippian series. G. A. Cooper (1942) used this break to delimit the Middle and Upper Devonian in the same area, and in the present paper it delimits beds at the Blocher-Trousdale-Blackiston level. Ulrich (1912) believes that the Huron, Olmsted, and Cleveland

> "constitute a single broadly conceived and diastrophically unbroken formation, or a group of three lithologically distinguishable members; . . . [and that the] work of Morse and Foerste made it highly probable that the Chattanooga as developed in different parts of Tennessee, may occasionally consist of representatives of only the Cleveland and in other cases of only the Sunbury shale of the Ohio section. Finally it had become reasonably probable, not to say positively assured, that the out crops of typical Chattanooga shale in east and middle Tennessee never included beds older than the Cleveland."

The present work does not confirm Ulrich's views.

Bassler (1932) regards the Hardin sandstone as the basal member of the Chattanooga shale in central Tennessee, but the Chattanooga basal sandstone is basal Trousdale, basal Dowelltown, or basal Gassaway in different localities. The Mount Pleasant "Hardin" conodonts cannot retain their Hardin origin and their Mississippian identity.

The Bransford sandstone and Swan Creek phosphate in all its varieties have the characters of reworked and transported material. The phosphatic Leipers limestone with *Cycloras* underlies the Chattanooga at some places along Swan Creek and in the adjoining territory to the east, and silicified boulders of Leipers limestone and

Cycloras occur in the Swan Creek phosphate (Bassler, 1932). Hayes (1895-1896) states that the minute coiled shells and phosphate ovules in the phosphate show evidence of transportation, and also that they occur in the underlying limestone. The Hardin sandstone and shaly phosphate no doubt furnished material for the Bransford sandstone. The conditions in the Swan Creek district furnished a perfect setting for faunal admixture in the basal Gassaway conglomerate and phosphate. This admixture is unmistakable in the Leipers fossils and is no less certain in the Mount Pleasant conodonts.

Maury shale.—The Maury shale, with its conspicuous phosphatic nodules which serve as a datum plane even under difficult conditions of exposure, has been prominent in black-shale literature as a connecting link between the black shale and overlying strata. Its status as a member of one or the other has been crucial to some of the theories relating to the Mississippian succession. The vertical relations of the Maury have been emphasized, but its lateral relations and composite character have not been recognized.

Safford (1869) included a layer of "kidneys", at the top of the black shale, as a part of the black shale group of Devonian age. Safford and Kellebrew (1900) named the Maury and defined it as a bed of green or greenish shale from a few inches to 4 to 5 feet thick, which contains concretions of calcium phosphate, in a layer 8 to 10, or exceptionally 18 inches thick, and included it with the Mississippian. Hayes (1894) included 3 to 4 feet of gray shale with a layer of phosphatic nodules occurring at the top of the black shale as a part of the type Chattanooga shale, and as a part of the Chattanooga in Polk and McMinn counties, Tennessee (Hayes, 1895); and in Alabama and Georgia (Hayes, 1892). Swartz (1924) regarded the Maury as "the broadly overlapping basal bed of the Ridgetop rather than of the Chattanooga shale, and as a condition not a chronological unit." Bassler (1932, p. 143) regarded the Maury as the "introductory stage of the succeeding formation no matter what that may be." According to Klepser (1937) and as quoted by Stockdale (1939), the Chattanooga everywhere grades upward into the Maury, and the Maury into the New Providence and Fort Payne. The Chattanooga and Maury are time-transgressing units representing the basal shore phases (the Chattanooga the more shoreward) of the sea advancing southward. The Chattanooga is in great part post-Kinderhook (almost entirely Osagian); in Alabama it is Warsaw, and possibly St. Louis, in age according to Klepser. These views of the different workers are correct within certain limits but are vitiated by too broad an application because of the uniformity in lithology of beds at the Maury horizon (and in overlying formations) and the failure to recognize the proper age of the beds involved.

The Maury shale has been assigned a thickness up to 20 feet and includes all undifferentiated material between the black shale and the next overlying identified formation. This has introduced undue uncertainty into the Maury problem. It is very doubtful if some of these undifferentiated beds are contemporaneous with the shale included with the type Maury in Maury County by Safford; it is even doubtful if all the shale included in the Maury of Maury County represents one period of deposition. While studying the bed at the Falling Run and Maury horizon for 400 miles from Indiana to Tennessee the writer seldom found over 1 to 2 feet of shale that

could not be separated from the overlying formations and conform to the characters determined for the Falling Run or Maury over the entire area.

The uniform appearance of the layer of argillaceous shale with nodules at the top of the New Albany in Kentucky and the Chattanooga in Tennessee, and its similarity in lithology to the overlying New Providence and Fort Payne have been misleading. The Bedford and Falling Run in central Kentucky and the Eulie shale in Tennessee conform to the characters of the Maury but belong to the Chattanooga. Fossils collected from the Maury at other localities identify it with the New Providence and Fort Payne. The lithology of the beds of these time divisions are so similar that they appear to be continuous, but their faunal content and the intervening Westmoreland black shale contradict this view.

The Chattanooga shale does not grade into the Maury but is overlain disconformably by the Maury. The Maury is the shoreward facies, not the seaward facies, of the Chattanooga or any other formation to which it is related. The Chattanooga is not a climbing facies but remains within the Tully to Sunbury time limits from Indiana and Ohio to Alabama.

The writer proposes the restriction of the term Maury to the bed of shale containing phosphatic nodules, commonly less than a foot thick, Osage in age, which overlies the Chattanooga shale. This definition excludes the Falling Run, Eulie, and the undifferentiated overlying beds, and limits the Maury to the time and conditions of formation of its most characteristic feature, the phosphatic nodules. This restriction will necessitate restudy and differentiation of the excessive thicknesses of shale usually assigned to the Maury but should help to clarify the Maury problem. In the present work the Maury has been confined to the limits proposed, and classified as Osage in age.

The Maury appears to be limited to the area bordering the Nashville dome, and the Falling Run occurs radially around, and perhaps originally encircled, the Lexington dome. Both nodule facies, in the main, are parallel to the Cincinnati arch, but their extent in a direction normal to the axis appears to be limited to a comparatively narrow belt.

The Kinderhook and Osage sequences represent a compound regressive-transgressive series, with the usual intermediate conglomerate replaced by beds of nodules. This series was formed around the secondary shores of the Cincinnati arch, and the seaward facies are oriented in opposite directions on opposite sides of the arch. Since the greater part of the Eulie and Westmoreland were removed by the Osage advance in central Tennessee, the regressive sequence is best represented by the Falling Run and related beds in Indiana and Kentucky. The summit bed of nodules ascends in time from the close of the Sanderson to the close of the Sunbury, and the series also must include the Rockford. The New Providence, the first of the transgressive beds, contains little evidence of a basal bed in Indiana or Kentucky. The Falling Run and Bedford with the usual complement of plant and invertebrate fossils extends south into Casey County, Kentucky. The Maury extends south from Casey County through central Tennessee on both sides of the Central Basin as the basal bed of the New Providence and younger formations. The hiatus between the sequences is

measured by the time from Gassaway to Fort Payne in Tennessee and Sanderson or Rockford to New Providence in Kentucky and Indiana.

The Falling Run and Maury sequences were formed at some depth, without erosion, during fluctuations of the sea level around the Cincinnati arch, but west of the Central Basin, in Tennessee, the Osage transgressive series contains, in addition to the bed of nodules, a basal conglomerate produced by the advance of the sea over a land mass, the southern primary boundary of the Osage sea. The conditions for the formation of the nodules and conglomerate were contemporaneous, but the shoreline conditions encroached on the site of nodule formation to some extent, and the Maury bed was reworked into the conglomerate base at some localities. These conditions are treated more fully in the following paragraphs.

Post-Chattanooga erosion.—The Kinderhook and Osage phases of the Maury are so similar that they cannot be distinguished by lithology, and the fossil-bearing localities are so few that the Maury units in most of Tennessee cannot be differentiated. The "two Maurys" have not been recognized together, and it has not been determined how much of the Kinderhook bed may have been removed by the advance of the Osage sea. The presence of the Westmoreland black shale above the Eulie at Bransford and Westmoreland, and at a few localities in adjoining counties in Kentucky, indicate that much of these beds was removed, and that the Maury in this region is mostly Osage in age. Only traces of arenaceous matter were observed in the Falling Run in all its range, or in the Maury, except west of the Basin. At Nashville the upper shale layer of the Maury is slightly arenaceous, and southwestward the Maury and all the beds of the Chattanooga become increasingly arenaceous.

The noticeable irregularity in the thickness of the Chattanooga west of the Basin suggests erosion. The regular pattern of distribution of the thin beds over much of Perry County indicates thin deposition and not erosion. In Hardin County the pattern of irregularity indicates erosion, and the time of the erosion is to be determined.

Swartz and Jewell held opposite opinions on the relation of the Maury to the Chattanooga. Swartz (1924) believed that the Maury was separated from the black shale by a marked unconformity and was basal Ridgetop, because in western Tennessee the black shale has been removed from many places, but the Maury is present whether the erosion was complete or only partial. He further supported his view with the evidence of Ridgetop and Fort Payne fossils collected from the Maury in Perry County.

Jewell (1931) thought the absence of the Maury from its horizon above the black shale at all but four places in Hardin County indicated that the erosion was subsequent to the Maury and that the Maury belonged with the black shale. He contended that if it were basal Ridgetop it should be present at all or nearly all localities.

Since it has been determined that beds identified as Maury occur in both the Chattanooga and overlying formations, the problem resolves itself into the determination of which division is present at any given locality and, thus, the time of the erosion. All but three of the following sections extending across Hardin County and

into Mississippi were formulated from data given by Jewell, and his classification and descriptive terms are used.

(The reader is referred to section 63 at Olive Hill for the first of the series.)

SECTION 66.—*On the headwaters of Steele Creek* (Jewell, 1931, p. 75)

	Feet
Ridgetop shale	
Maury: glauconitic sandstone	1.20
Phosphatic nodules	0.33

SECTION 67.—*On the headwaters of English Creek* (Jewell, 1931, p. 40, 73)

	Feet
Ridgetop shale	
Basal layer: dark-green phosphatic sandstone a few inches thick;	
Thin dense limestone with phosphatic nodules; probably reworked Maury	
Unconformity	
Maury: layer of phosphatic nodules	0.20
Greenish-gray sandy shale with a few limestone nodules in upper part	1.33
Dark-blue phosphatic limestone	0.80
Black shale	

SECTION 68.—*On Cain Creek, just south of the Savannah-Walnut Grove road, Hardin County, Tennessee* (Jewell, 1931, p. 73)

	Feet
Ridgetop	
Hardin, greenish-gray phosphatic sandstone with nodules and chert pebbles derived from the Ross limestone	2.50
Ross limestone	

SECTION 69.—*On Holland Creek, Hardin County, Tennessee* (Jewell, 1931, p. 40, 73)

	Feet
Ridgetop, basal glauconitic sandstone with phosphatic nodules, chert, limestone, and sandstone pebbles derived from the Maury. In places the pebbles are so thick that the sandstone passes into a conglomerate	1.67
Maury, phosphatic green and gray shale and sandstone, principally sandstone	6.00
Chattanooga black shale with interbedded sandstone	8.00

(The reader is referred to section 64, at Lowryville, for the next section in the series. Sections 67, 68, 69, and 64 are in line east and west within 5 miles of section 68.)

SECTION 70.—*On Dry Creek near Dry Creek School, Hardin County, Tennessee* (Jewell, 1931, p. 74)

	Feet
Ridgetop: dark shaly limestone	
Basal: dark pyritic limestone	1.00
Shale	0.60
Dark pyritic sandstone with a little shale	2.00
Chattanooga shale, very platy with interbedded sandstone	0.80
Hardin sandstone, dark gray, cross bedded, pyritic with a small amount of interbedded black shale	4.50
Pyburn limestone	

SECTION 71.—*On Dry Creek, near Walnut Grove, Hardin County, Tennessee* (Dunbar, 1919, p. 126)

	Feet
Ridgetop	
Unconformity	
Chattanooga formation	
Hardin sandstone member	
Massive, compact layer of fine-grained gray sandstone with a 6-inch layer of conglomerate at the base.	
Pebbles mostly angular, chiefly composed of black and gray chert. Associated with the pebbles are numerous pieces of flat fish bone	3.00

"It [Hardin ss.] may, however, be a basal member of the Ridgetop." (p. 92)

SECTION 72.—*On Yellow Creek, near center of section 27, Tishomingo County, Mississippi* (Dunbar, 1919, p. 92)

Hardin sandstone as in section 71 at Dry Creek.

SECTION 73.—*In Tishomingo County, Mississippi* (Morse, 1928)

Carmack limestone

Devonian
Upper series
Whetstone Branch shale, "The Whetstone Branch formation is usually a black shale, though it does contain a few, mostly thin, sandstones. In a number of places this formation is represented only by a rather prominent sandstone layer, which has a conglomeratic base and in some places rests unconformably on older formations. In other places typical black shales underlie and overlie it in such relations as to show that the layer is separated from the underlying shales by a contemporaneous erosion surface rather than by an unconformity."
Oriskanian

The position of the sandstone beneath the black shale in sections 63, 64, and 70 identify it as Hardin. No basal conglomerate has ever been mentioned with the Hardin where it has been identified with certainty; the basal conglomerate in sections 68, 71, 72, and 73, in the absence of confirmatory evidence, casts doubt on the Hardin classification.

The black shale in sections 69 and 70 represents the Dowelltown because platy shale and interbedded sandstone are characteristic of the Dowelltown west of the Basin.

No limestone occurs from the bottom of the Gassaway to the top of the Westmoreland in any other area, but it is common in the Ridgetop shale. Limestone occurs in the Maury in section 67, but it is not clear why Jewell separated the basal Ridgetop and Maury in this section. A sandstone occurs between the black shale and the Ridgetop proper in sections 66 to 71, except 64, and a conglomerate occurs in 68, 69, 71, and 73; the sandstone overlies the nodules in 66 and 67. The writer is of the opinion that the Maury in these sections (possibly section 58 is an exception) is basal Ridgetop instead of the summit bed of the Chattanooga, and that the "Maury" sandstone in sections 68, 71, 72, and 73 is basal Ridgetop also. This classification implies post-Chattanooga erosion. Sections 63, 64, and 73, at the middle and ends of the region, show the Chattanooga fully represented. Various amounts of the Chattanooga were removed at different localities leaving 8 feet of Dowelltown in section 69, only 10 inches of the Dowelltown and the Hardin sandstone in section 70, and possibly all the Chattanooga was removed at other places. As the Ridgetop overlapped this region phosphatic sandstone, conglomeratic limestone, and nodules were deposited. The sandstone and conglomerate predominated southward, accompanied by contemporaneous erosion, and all are to be classed as basal Ridgetop.

The sequence of beds in other counties west of the Basin indicate a post-Chattanooga age for the Maury in this region. South from Nashville the Ridgetop, Maury, Gassaway black shale, and Bransford sandstone, or its phosphatic facies, extend into Lewis County. The black shale thins and feathers out at the Hickman-Lewis County line, and in Lewis County the Maury and Ridgetop overlap the basal phosphate bed (sections 56, 57). East from Flat Woods along the Buffalo River, the members of the Chattanooga wedge out—first the black shale, then the shaly phosphate, and finally the Hardin sandstone, leaving only the Maury and the overlying Ridgetop, which continue and overlap Silurian beds. South from Buffalo River in Wayne

County the Maury with the Ridgetop or Fort Payne overlaps different levels of the Chattanooga, Silurian, and Ordovician beds. Available evidence indicates that the Maury is Osage in age in most of central Tennessee.

CHATTANOOGA SHALE IN EASTERN TENNESSEE

Swartz (1924) correlated the Chattanooga in the type area and along the Cumberland escarpment with the Mississippian, Cleveland, Bedford, and Sunbury of Ohio and classified the Chattanooga of central Tennessee as probably entirely Cleveland in age. Later (1927) he designated the three divisions as Cumberland Gap, Olinger, and Big Stone Gap respectively. The Olinger contains Mississippian faunas, Bedford in age at Apison and late Cuyahogan at Rutledge, according to Swartz. In his classification the Big Stone Gap is Mississippian by virtue of its position above the Olinger; the upper Cumberland Gap is Mississippian because it interfingers with the Olinger, and the lower Cumberland Gap is Devonian because it interfingers with beds with a Chemung fauna. The Mississippian assignments in all areas are based entirely on the Olinger faunas.

Swartz held that the "Portage" wedges out westward and is overlapped by the Chattanooga, but this opinion cannot be sustained. The "Portage" may retain its individual characters farther west than the "Chemung". There is evidence that this condition prevails over the entire New Albany area, and that the "Portage" type of sediments was more widely distributed than the "Chemung" type. However, the sections of Swartz show no more reason for correlating the lower Cumberland Gap with the "Chemung" than with the "Portage", both of which grade westward through sandy shale and interfinger with sandy black shale. A comparison of sections in the two areas shows that the entire Devonian group of eastern Tennessee is represented in central Tennessee with similar stratigraphic boundaries.

The section exposed at the type locality represents only about one third of the thickness of the Chattanooga shale in that region. According to different authorities the Chattanooga is 12 to 35 feet thick in the counties surrounding the type region and 18 to 35 feet thick in Georgia and Alabama. There has been no factual evidence presented to indicate that the Chattanooga of the type region may not contain beds of Devonian age. The occurrence of Devonian faunas in Alabama and through central Tennessee evince the spread of the Devonian sediments westward and southward around and beyond Chattanooga.

Swartz (1929) failed to recognize the Devonian-Mississippian boundary in eastern Tennessee and postulated continuous deposition across the boundary without a regression of the sea. The break between the two systems has been determined and specified in most other areas and is especially apparent in central Tennessee; it is very probable that it can be determined in eastern Tennessee.

CHATTANOOGA SHALE IN ALABAMA

The Chattanooga shale extends into Alabama across the full width of the State, opposite Marion and Hardin counties, Tennessee. Butts (1926) reported the

stratigraphy of the Chattanooga in Alabama and gave its distribution as extending from the Coosa River northwestward, and south to Birmingham. He gave its thickness as averaging about 20 feet, ranging from 2 to 10 feet in Lauderdale and Madison counties.

He states:

"Where the Chattanooga is best developed it is a densely black highly fissile shale. At Blount Springs it includes one foot of sandstone near the middle and at Arkdell, Lauderdale County it includes thin sandy lenses and passes upward into a few feet of gray shale and sandstone that possibly should be included with it. In the northwestern counties it has at the base about one foot of sandstone, which is thicker in parts of western Tennessee, where it is known as the Hardin sandstone member."

Lingula melie and *Orbiculoidea*, and species of conodonts collected at New Market, are listed as the principal fossils. He obtained *Barroisella subspatulata* from beds below the middle of the Chattanooga at Blount Springs (Butts, 1927), and in a letter to the writer located *Barroisella* below the middle sandstone layer.

Butts concurs with the opinion of Ulrich that the Chattanooga of southwest Tennessee and Alabama is all that is left of the thick mass of Devonian and Mississippian shales that has overlapped from Kentucky and Virginia across Tennessee, and is to be correlated with the Sunbury shale, from which its Mississippian age follows.

Holmes (1928) described 36 species of Early Mississippian conodonts from the Chattanooga at Huntsville, Madison County, Alabama, but did not designate from which levels in the Chattanooga they were collected. *Spathodus subrectus* (Holmes), *Polygnathus rhomboidea* Ulrich and Bassler, *Polygnathus concentrica* Ulrich and Bassler, *Polygnathus gyralineata* Holmes, *Palmatolepis elongata* Holmes, *Palmatolepis perlobata* Ulrich and Bassler, *Ancyrognathus inequalis* Holmes, *Lonchodina irregularis* Holmes, *Lonchodina discreta* Ulrich and Bassler, *Prioniodus alatoides* Holmes, and *Palmatodella delicatula* Ulrich and Bassler are common to the lower Blackiston in Indiana, where they are associated with *Barroisella campbelli*. *Hindeodella tenerrima* Holmes, *Synprioniodina plana* Holmes, *Prioniodina separans* Holmes, *Spathodus subrectus* (Holmes), and *Spathodis rectus* Holmes are common to the upper New Albany in Indiana, where they are associated with *Lingula melie* and *Orbiculoidea herzeri*.

The black shale with interbedded sandstone and the basal sandstone at Arkdell are identified as Dowelltown and basal Hardin, of Devonian age; and, in central Alabama, the lower black shale is identified as Dowelltown; the middle sandstone is basal Bransford, and the upper black shale is Gassaway,—both Mississippian in age.

The Chattanooga of Alabama corresponds to the Chattanooga and New Albany in other areas in faunal content and stratigraphic relations, as far as can be determined from available data. The stratigraphic framework erected for the New Albany and Chattanooga extends with all essential features through the black shale in all areas. A more discriminating study of the beds of Alabama and zonal collection of conodonts should verify these correlations.

GENERAL RELATIONS OF THE NEW ALBANY SHALE

The separate study of the New Albany, Chattanooga, or Ohio shale in the past resulted in somewhat different views, and some erroneous attempts to apply the conclusions in one area to another. Any conclusion must satisfy conditions over the entire black-shale area. Each State contributes some evidence not apparent in the other States, and the detailed tracing of the New Albany through the several States revealed stratigraphic features which permit firmer conclusions on some phases of the New Albany problem and may help clarify some of the controversial questions.

Two outstanding features of the New Albany are the wide distribution of the divisions of the type section and the stable conditions and life environment over long periods of time. The time units of the New Albany are represented in nearly all the area under study, and there are indications that they are fully represented in the strata of the Mississippi Valley.

The New Albany shale contains the faunal expression of distinct facies provinces whose faunas can be compared in time values only by means of their stratigraphic relations. To attempt to correlate the Blackiston with any specific formation in the Upper Devonian is futile, for apparently it was contemporaneous with all the Upper Devonian. The forces and conditions that produced the numerous well differentiated categories of the late Devonian and early Mississippian standard scale were in great part inoperative in the New Albany area. The black mud was replaced in some areas, at times, by other types of sediments, but regularly returned, apparently without change. This independent course was broken but once with a change in black shale facies and but twice with changes in black shale life. The boundary between the lower and upper Blackiston separates the two facies of black shale; the Blocher-Blackiston and Blackiston-Sanderson boundaries separate the three New Albany life zones.

The Portwood formation with *Hypothyridina* extends about 100 miles along the southeast quarter of the Cincinnati dome in Kentucky. The *Schizobolus* zone extends along the Appalachians from New York to eastern Tennessee, and in the Trousdale shale, from central Tennessee to Bath County, Kentucky, and to Hayden, Indiana, 50 miles north of the Ohio River. Westward *Schizobolus* occurs in Arkansas and Texas (G. A. Cooper, 1942). The Blocher *Leiorhynchus* fauna overlies the *Schizobolus* zone and occurs only north of the Ohio River, in Indiana. There is no indication of the *Leiorhynchus* assemblage between New York and southern Indiana. Although there is no direct evidence to support the view, this fauna must have entered southern Indiana from a northern route.

After a break in deposition the Blackiston appeared with the *Manticoceras-Barroisella* fauna and a new conodont assemblage, accompanied by a sweeping shift of facies; the site of limestone deposition was transferred to the Mississippi Valley. *Manticoceras*, *Barroisella*, and *Spathiocaris* compose the fauna of the argillaceous shale, and the *Ancyrodella* group of conodont genera dominates the black shale fauna. *Barroisella* and *Spathiocaris*, together, occur in the basal Blackiston in the Delphi shale in northern Indiana; and in the New Albany in southern Indiana, Ohio, Kentucky, and Tennessee. *Barroisella*, alone, occurs in the lower Blackiston mem-

ber in all areas from Michigan to Alabama; and in the Mountain Glen shale of southwestern Illinois. The Blackiston conodonts show generic affinities with assemblages in other areas (Table 3).

Prioniodus alatoides Holmes, *Palmatolepis perlobata* Ulrich and Bassler, *P. glabra* Ulrich and Bassler, *Polylophodonta concentrica* (Ulrich and Bassler) Branson and Mehl, and *Palmatodella delicatula* Ulrich and Bassler are widely distributed species, and each occurs in three or more of the following formations: Blackiston of Indiana, "Hardin" of Tennessee, Chattanooga of Alabama, lower Arkansas novaculite of Arkansas, and lower Woodford of Oklahoma. Ten species from the lower Blackiston occur in the Grassy Creek of Missouri. *Barroisella* and the conodonts show a wide distribution of beds contemporaneous with the Upper Devonian Blackiston.

There is no evidence that any part of the Cincinnati arch, north of the Nashville dome, was land during Blackiston deposition. Shallow water prevailed over the arch south of the Cincinnati dome, with shoals and probably small land masses along the Nashville dome. Elsewhere the Blackiston sediments were laid down at a depth below the reach of wave action. The layers of gray shale, even where only a half to an inch thick, retain their argillaceous character and show little carbonaceous matter. This condition continued across the Cincinnati arch in the north, but to the south only black shale was deposited on the crest of the arch.

The change of facies of black shale occurring at the beginning of the upper Blackiston was due to the withdrawal of surplus argillaceous elements. This left the New Albany sea unhampered in the production of a pure black mud facies containing more sulphur, fixed carbon, and oil, and less ash, than the preceeding facies. This facies continued through the remainder of the New Albany.

The New Albany black-mud environment was indifferent to the minor changes in other facies provinces and responded only to breaks of major importance, which involved extensive withdrawals of the sea and radical changes in faunas. A break of this magnitude occurred between the Blackiston and Sanderson, which represents a pause in sedimentation between the completion of the final stage of the Upper Devonian and the initial stage of the Mississippian. The interval was a time of adjustment of new sea connections and the introduction of new life forms with Mississippian affinities. Therein lies the importance of the break. Sixty-nine species of conodonts have been reported from the upper New Albany. Fourteen species are common to Devonian formations, 18 to Mississippian, 3 to Devonian and Mississippian, and the remainder are not known outside the upper New Albany. The characteristic Devonian genera are absent, and the Mississippian species are represented by a great many individuals. The upper New Albany brachipoods and crustaceans are not known in the Devonian. The Mississippian stamp of the conodont genera has been the deciding factor in determining the Mississippian age of the upper New Albany.

The upper New Albany flora first appeared at the beginning of the Sanderson. *Steloxylon irvingense* was collected at the base of the Sanderson, *Archeopitys eastmani*, a few feet higher. Plants are abundant at the Bedford-Falling Run horizon from Junction City, Kentucky, to New Albany, Indiana, but have not been collected south of Liberty, Kentucky. No plants were collected from the Maury shale in

Tennessee, although careful search was made at every outcrop studied. The type of plants and their condition of preservation indicate short transportation and a near by source, and point to the Cincinnati dome as the land mass where they flourished.

There was a pause in deposition of black shale at the close of the lower bed of the Sanderson (D1, Fig. 3) west of the Cincinnati arch, during which a layer of phosphatic concretions was formed without black shale. This layer was traced for 60 miles in Indiana and Kentucky.

The Falling Run nodules were formed during conditions favorable for black-mud life but without the deposition of black shale. A complexity of environmental conditions is revealed at the Falling Run horizon. The Bedford and Underwood faunas, which are regarded as closely related provincial assemblages in similar facies, occur close to the crest of the Cincinnati arch, on opposite sides. They occur in the midst of the black-mud fauna, which shows no provincial pattern with reference to the arch. Mingled with the three assemblages are the land plants, in both facies, on both sides the crest of the arch. The Bedford fauna appeared first but probably was coeval in great part with the Underwood fauna. The flora attests the synchroneity of the three faunas.

The probable synchronous development of latest Devonian and earliest Mississippian life in separate basins has long been recognized, but the conditions in the Sanderson and Bedford show the arrival of Mississippian forms, their continued existence among Devonian species in the same brackish sea, and the final burial of both forms, with land plants, both above and below the Bedford fauna.

With the evidence now available the Sanderson can not be correlated closely with any formation of the standard column. Its chronological position is between the Chagrin and Bedford, interbedding to some extent with the Bedford, but as the Sanderson thins eastward from Cleveland, Ohio, the Bedford draws near the Chagrin and the Sanderson seems to pass into a disconformity. The crustaceans of the Sanderson are common to the upper Woodford of Oklahoma; diagnostic genera and species of conodonts are common to the pre-Welden of Oklahoma and Bushberg of Missouri; but the exact relations to the Kinderhookian section is not apparent.

The new genera determine the Mississippian affinities of the upper New Albany but not the exact position in the Early Mississippian classification. Ulrich (1911) introduced the Chattanoogan series, (Cleveland to Sunbury), a sequence older than the Kinderhookian Louisiana. This classification was adopted by some authorities. Caster (1933) substituted the Oil Lake series and the Crawford subseries for the Chattanoogan, minus the Cleveland, and recognized a disconformity of serial rank between the Bedford and Berea.

The present classification of the New Albany and the correlation of the Bedford, Underwood, Hamburg, and Glen Park calls for a new alignment of beds at this horizon. The location of the lower Mississippian boundary at the base of the Sanderson would do little harm to Ulrich's theory of the genesis of the Mississippian, but the recognition of the Upper Devonian age of the Huron and Olmsted and the correlation of the Bedford and Hamburg strip the Chattanoogan of most of its units as a distinct series and places them in closer relation with the Kinderhookian.

By definition the New Albany terminates with the black shale, but the upper limit

of the New Albany Mississippian faunal zone has not been determined. The Rockford facies fauna is not comparable to the upper New Albany fauna, and there is no evidence to indicate the time relations of the lower New Providence to the Rockford, New Albany, or upper New Providence. The Rockford long furnished the only faunal evidence between the Genesee fauna at the base of the New Albany and the fossiliferous limestone horizon in the upper New Providence, and there still is no evidence that determines the Osage or Kinderhookian age of the lower New Providence.

There is no definite faunal or physical evidence of disconformable relations between the New Providence and Rockford or New Albany. Transition beds between the New Albany and New Providence have been reported, but evidence given in this paper place these beds in the New Albany. The absence of the Rockford in Kentucky seems to imply disconformity, but Kindle (1899) regarded the Rockford as contemporaneous with the New Providence.

Section 74 throws some light on the structure of the New Providence.

SECTION 74.—*At the Goetz quarry, sw¼sw¼ sec. 3, T.3 S., R.6 E., on highway 62, ½ mile west of the city limits of New Albany, Indiana*

New Providence
Sandstone and shale
Shale, light olive-drab with red and yellow streaks, bands, and mottling. Many small worm borings with iron-stained fillings. Weathers to lumpy masses and particles. Iron-stone concretions with concentric outer layers which separate on weathering are common. Joints prominent and abundant but very irregular in arrangement.
Shale, 8 feet thick. Interbedded layers of olive-drab shale as above and dark-gray shale as below.
Shale, dark gray, slightly harder than that above, thinly bedded, weathers to chips. Joints not prominent. Large iron-stone concretions with the cone-in-cone outer layer occur at different levels. Numerous fissures filled with olive-drab shale as in the upper bed extend to the bottom of the exposed section. These veins of olive-drab shale are 3 to 5 inches wide and are sharply delimited from the surrounding gray shale. The enclosed olive-drab shale is laminated, and a joint extends vertically through the middle of each vein. A number of these fissures were observed over about 75 feet of quarry face.

The conditions in this section were observed during work in the quarry when fresh material was exposed. Weathering produces changes in color and texture of both facies which gives the appearance of uniformity throughout the New Providence. A small *Lingula*, a minute *Orbiculoidea*, and *Conularia* have been collected from the lower bed at other localities, but no other fossils are known.

The New Providence is about 200 feet thick at New Albany, and the Osage fossils occur in the upper bed in this area and also at Button Mould Knob in Kentucky. No evidence is at hand to evaluate the hiatus between the beds, and it can be dated only as prior to the arrival of the Osage fauna. However the conditions then present suggest caution in accepting the New Providence within its present boundaries, in the New Albany, Indiana, area as a stratigraphic unit, and in determining its lower limits and relations. The microfauna of the lower bed may decide its relations. Section 12, at Pine Lick in Marion County, Kentucky shows the lower bed of dark-gray shale reduced to 8 feet from the thickness of about 100 feet at New Albany, in a distance of about 50 miles.

The Kinderhook and Osage groups are generally disconformable in their grosser relations. Although the relations of the New Providence with subjacent strata

west of the Cincinnati arch is not clear, an erosional disconformity is indicated in other parts of the New Albany area. In southeastern Estill County, Kentucky, the New Providence advance was accompanied by erosion as shown in section 75.

SECTION 75.—*At the roadside on two adjacent hills, 2 miles south of Ravenna, Estill County, Kentucky*

New Providence
Weathered sandy shale, in spots almost pure sand.
Weathered bed, 6 feet thick, of gray sandstone pebbles from 3 inches in diameter down to sand grains, with remnants of black fissile shale.

Sanderson fissile black shale.

In central Tennessee and the bordering counties of Kentucky, the New Providence advance removed all but remnants of the Westmoreland and Eulie shales without leaving a conglomeratic deposit, but at some localities phosphatic concretions and Osage fossils were locally deposited. West of the Central Basin the advancing Ridgetop sea removed part or all of the Chattanooga in different localities and deposited phosphatic nodules, sandstone, and conglomerate as parts of a basal Mississippian layer.

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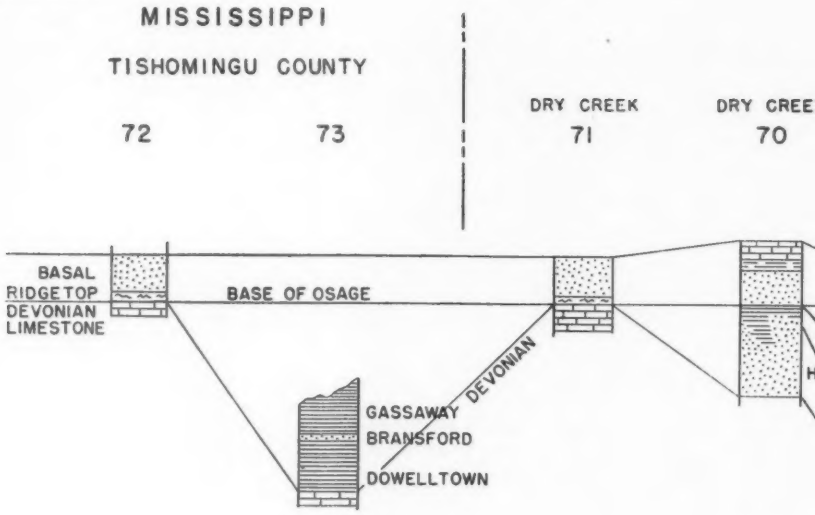
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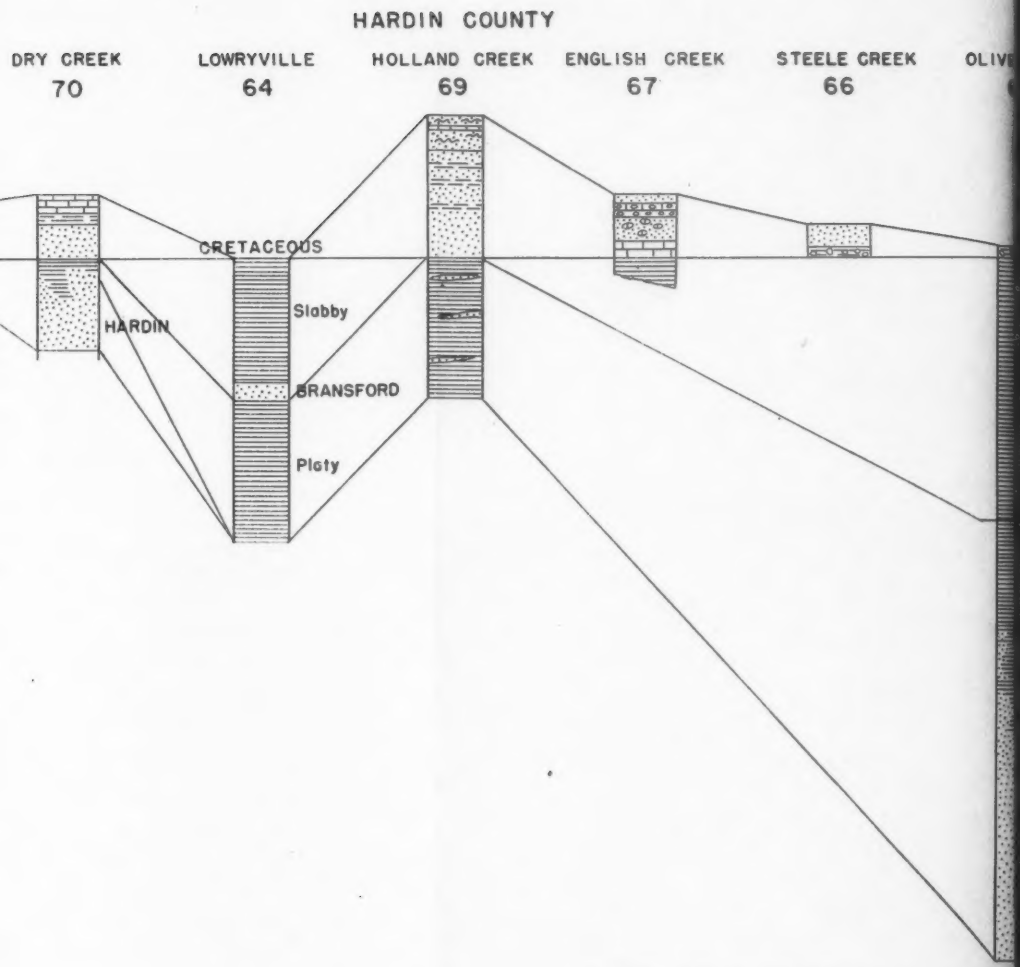

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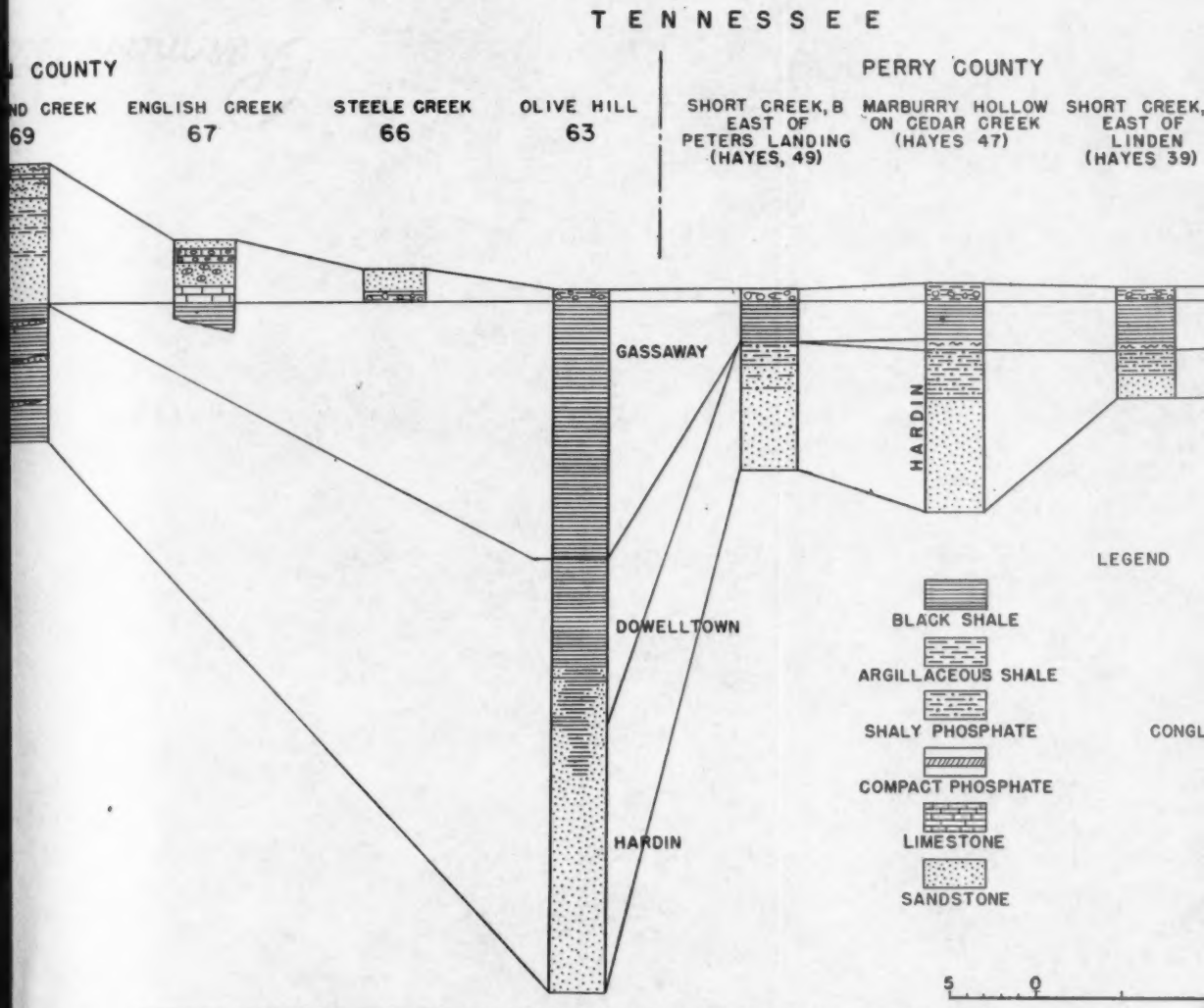

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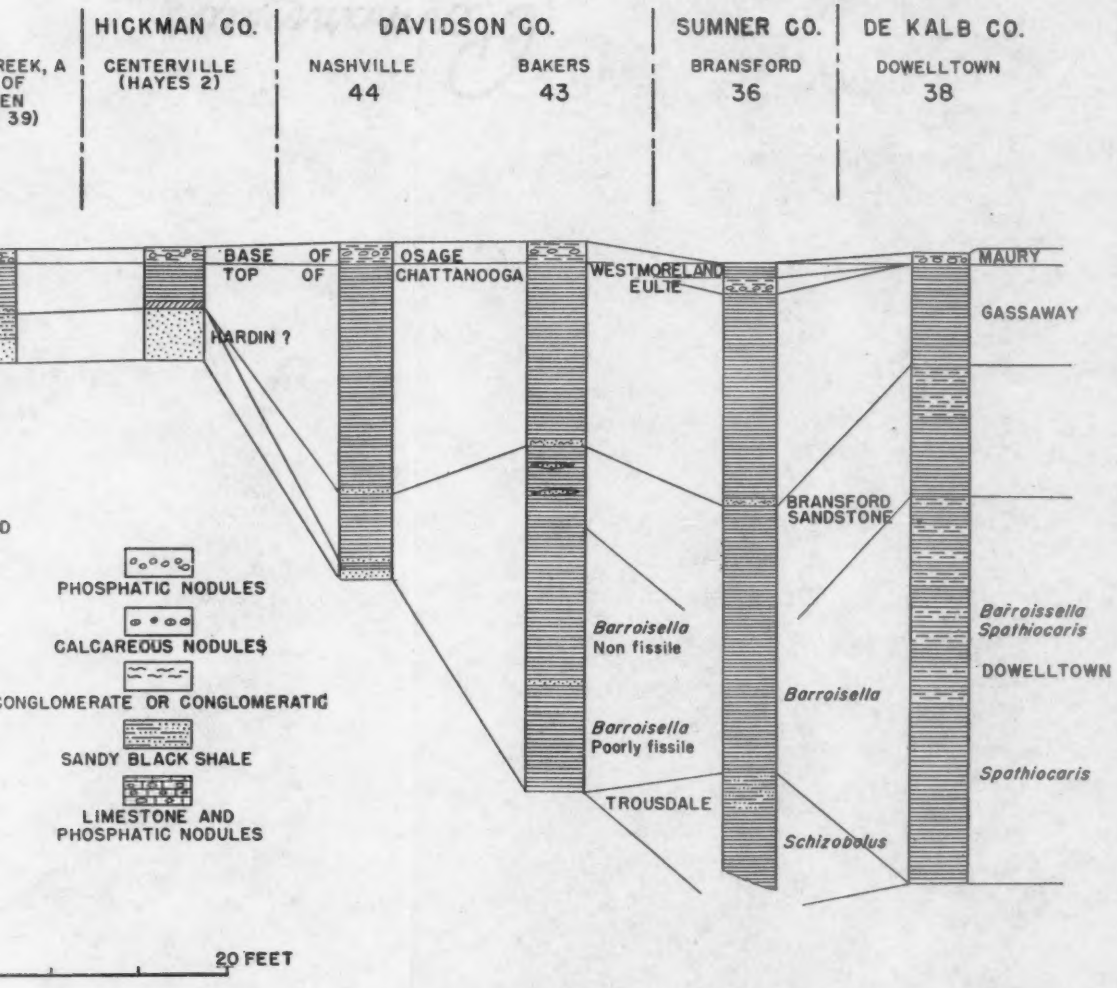
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